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Voluntary environmental regulation and export performance of Chinese solar energy industry

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The shortage of traditional fossil energy resources, together with the pressure of environmental pollution, has stimulated the growing trade of solar energy products in China. The purpose of this article is to examine the impact of voluntary environmental regulation on China's solar energy industry trade flows. To this aim, the paper selects panel data of Chinese solar energy industry exports to 46 countries from 2002 to 2020 and uses the fixed effect regression model. The results show that export destination countries' voluntary environmental regulation has a significant positive impact on China's exports, whereas the bilateral gap in voluntary environmental regulation has a negative effect. Further evidence suggests that reducing the bilateral gap in voluntary environmental regulation has more obvious promoting effect of the exports to developed countries than to developing countries, verifying that there is country heterogeneity. Besides, more trade friction weakens the role of the host countries' voluntary environmental regulations in promoting exports. The implication of this paper is that voluntary environmental regulation have economic effects including demand effect, information effect and the common language effect, which is incredibly significant to promoting the sustained and stable development of the solar energy trade.

KEYWORDS

solar energy industry, export, voluntary environmental regulation, ISO 14001, certification

1 Introduction

With the increase of prominent environmental problems, traditional energy transformations have caused wide concerns in the world. Both developed and developing countries vigorously attempt using renewable energy sources such as wind and solar power to reduce emissions of pollutants (Hu et al., 2021). As a relatively mature industry system in the renewable energy industry structure, the solar energy industry is an important guarantee in promoting the transformation of China's energy structure. China has overtaken Japan as the world's largest solar energy exporter since 2008 and remained the export leader for 12 years, according to UN Comtrade. By the end of 2021, China's solar energy industry's exports totaled about $61.827 billion, accounting for 51.4% of the world's total solar energy industry's exports. The fast-growing Chinese solar energy industry provides an important sample for renewable energy trade studies.

In recent years, many scholars have studied trade competitiveness and the influencing factors of the renewable energy industry in various countries from different dimensions and at different levels, putting forward constructive solutions for creating competitive advantages in trade (Lacerda and van den Bergh, 2014; Zhang et al., 2016; Wang, 2019). The impact of environmental regulation on trade has gradually attracted extensive attention from scholars both at home and abroad. The literature generally revolves around two hypotheses: one is the pollution haven hypothesis, which argues that countries with strict environmental regulations will face higher regulatory standards for their domestic industries and thereby increase their production costs, which in turn make them lose trade competitiveness and ruin exports. The opposite is true for countries with lax environmental regulation (Copeland and Taylor, 2003). The founders of the other hypothesis, Porter and Van der Linde (1995), challenge the pollution haven hypothesis by arguing that although at first glance strict environmental regulation may seem to harm economic development, the innovation induced by strict regulations can actually lead to a country's comparative advantage in advancing technology by making itself a net exporter of advanced technologies. Based on these two hypotheses, a number of scholars have tried to elucidate the relationship between environmental regulation and trade with the help of rigorous empirical tests, but the conclusions have not been uniform (Arouri et al., 2012; Hering and Poncet, 2014; Shi and Xu, 2018; Liu et al., 2021).

However, previous literature have focused on the impact of mandatory environmental regulatory tools and market-based environmental regulatory tools on international trade. By contrast, there is a lack of research on voluntary environmental regulatory instruments. Voluntary environmental regulation refers to an agreement, commitment, or program proposed by an industry association, enterprise, or other entities, in which the enterprises decide whether or not to participate, and which is essentially an agreement without mandatory binding (Blackman et al., 2010). Among them, ISO 14001 certification is the fastest growing and most clearly regulated voluntary environmental management standard published in the form of ISO international standard in recent years (Shu et al., 2016). Moreover, the voluntary ISO 14001 certification of firms proves to some extent that they have the objective conditions for technological innovation and therefore fit better into the theoretical category of the Porter's hypothesis (Jiang et al., 2020).

However, few scholars have studied the impact of environmental regulation on the renewable energy industry, especially the impact of voluntary environmental regulation on the solar energy industry. Theoretically, considering the policy and market environment of the importing country, the level of environmental regulation of the importing country also affects the trade. As a renewable energy industry, the solar energy industry has its own environmentally friendly characteristics. Developed importing countries tend to have more stringent levels of environmental regulation. The smaller the gap in the level of environmental regulation between the importing and exporting countries, the greater is the likelihood of trade. On the other hand, importers with lower levels of environmental regulation will also prefer renewable energy products from countries with higher levels of environmental regulation. In other words, a better level of environmental regulation in export will facilitate trade in the solar energy industry to some extent. This study addresses the important question on what the reality of trade is for the solar energy industry in China.

For this purpose, we use the data on export between China and 46 countries, covering the product categories of the solar energy industry. The sample countries are the 46 importing countries for China in 2020 that account for 86.3% of China's solar energy industry's exports. We chose 2002-2020 as the time interval for sample. On this basis, this study uses the number of ISO 14001 certifications as a proxy variable for voluntary environmental regulation and panel regressions to examine their impact on the solar energy industry's exports; the study further measures the interaction effects arising from trade frictions using technical barriers to trade (TBT) as a moderating variable. The results show that the strict environmental regulations of importing countries have a significant positive impact on the export of the solar energy industry's products. Further investigations have suggested that narrowing the bilateral voluntary environmental regulation gap is more conducive to improve exports to developed countries than developing countries. In addition, the results demonstrate that an increase in TBT in importing countries and China will weaken the positive impact of the voluntary environmental regulation of the importing countries on China's exports of the solar energy industry, however this increase in TBT will not affect the impact of voluntary environmental regulatory convergence.

This study mainly contributes to the following three aspects: 1) previous studies have mostly focused on the impact of environmental regulation on the trade of polluting industries, but rarely on the impact of the renewable energy industry, especially the solar energy industry. The latter studies have mainly focused on developed countries in Europe and the United States, and there is a lack of such studies in developing countries, especially in China. Given the differences in national circumstances, especially the stage of development, the results of existing studies may not be applicable to China. To this end, this study provides empirical evidence for China's solar energy industry and to some extent fills the research gap in the relationship between the two. 2) While most of the existing literature takes the exporting country as the perspective of the study, this article innovates that perspective by considering the policy and market environment of the host country, focusing on the level of voluntary environmental regulation in the host country and the impact of the gap between the level of voluntary environmental regulation in the two countries on the trade of solar energy products. 3) In recent years, with the rise of trade protectionist ideology, TBT have become the government's preferred tool to achieve trade protectionist goals and have a profound impact on trade in the Chinese solar energy industry. Therefore, this study considers this reality and uses TBT as a moderating variable to further explore whether it affects the impact that voluntary environmental regulation has on the solar energy industry.

The remaining article is organized as follows: Section 2 reviews the literature on trade in the renewable energy industry and impact of environmental regulation on trade. Section 3 analyzes the structural characteristics of the world solar energy industry trade network. Section 4 presents the research design, which includes data organization, variable description, and econometric model setting. Section 5 reports the empirical results, covering benchmark

regressions, robustness tests, heterogeneity tests, and moderating effects analysis. Section 6 discusses our main findings and conclusions.

2 Literature review

2.1 Renewable energy industry trade

At present, with frequent occurrences of extreme global weather phenomena and increasingly serious climate warming problems, the development of renewable energy industry such as nuclear power, wind power, hydropower, photovoltaic and biomass and the trade of renewable energy industry have become an inevitable requirement for the international community to achieve sustainable development (Moriarty and Honnery, 2016). Early studies on trade in the renewable energy industry have focused on developed economies such as the United States and Europe (Wietschel and Seydel, 2007). Due to the vulnerable ecosystem, developing nations are more concerned about environmental sustainability in recent years (Ali et al., 2022). More and more scholars have shifted their attention to developing countries, arguing that developing countries are also rich in renewable resources and have great trade potential (Emodi et al., 2014; Erdiwansyah et al., 2019).

The trade competitiveness of countries in renewable energy industry has been a subject of extensive scholarly interests. Zhang and Liu (2013) have analyzed the international competitiveness of China's renewable energy industry and revealed the strengths and weaknesses of its trade competitiveness. Shuai et al. (2022) constructed a new multidimensional evaluation index to estimate the international competitiveness advantage of renewable energy products exported by the United States, China, and India, and the results of the study indicated that the overall international competitiveness of renewable energy products in the United States is strong, while in China and India, it shows rapid growth. Apergis and Payne (2010) developed a multivariate structural model of the relationship between trade competitiveness and economic growth of the renewable energy industry in 20 OECD countries between 1985 and 2005, showing the relationship between trade competitiveness of the renewable energy industry and its economic growth. They showed that there is a two-way causal relationship between trade competitiveness and economic growth in the renewable energy industry in the short and long terms.

Scholars have also analyzed the factors affecting the trade of the renewable energy industry in terms of institutional and economic aspects, such as trade barriers (Shadikhodjaev, 2018), government subsidies (Johnson, 2013), and import demand (Wang et al., 2016a). For trade of the solar energy industry, Onno et al. (2018) studied the impact of domestic renewable energy policies on solar energy exports in 40 countries over the period 1995–2013 and showed that renewable energy policies were positively associated with export performance, however this boost was short lived in the solar PV sector. Cao and Groba (2015) examined the effects of government policies, technological innovation, and market size on solar energy industry exports, and the results show that Chinese provincial government public R&D expenditures have a significant positive effect on solar energy industry trade. Kim and Kim (2015) conducted an empirical analysis of panel data on solar PV and wind energy technologies in 30 countries and showed that international markets might have an impact on domestic R&D of mature technologies, while enhancing domestic R&D would have a facilitative effect on international trade.

Other scholars have in addition studied trade in the renewable energy industry from the perspective of trade complementarity (Holzer and Zhang, 2008), as well as trade networks in the renewable energy industry (Guan et al., 2016).

2.2 Environmental regulation and trade

With the longitudinal development of economic globalization and international trade liberalization, the relationship between environmental regulation and trade has become a hot topic in academia. Research on the relationship between these two is inconclusive, and some scholars have found a positive impact of environmental regulation on trade through empirical studies (De Santis, 2012; Zhu et al., 2019), whereas others have reached the opposite conclusion (Babool and Reed, 2010; Wang et al., 2017), while some others have argued that the two do not have a significant association (Caporale et al., 2010; Wang et al., 2016b).

It is generally accepted that environmental regulation in a country can affect the country's trade by influencing technological innovation. Technological innovation has been identified in studies as an important non-price factor that positively affects bilateral trade between countries (Eaton and Kortum, 2002). In the case of China, a large number of empirical studies have found that innovation activities have a positive impact on China's export performance through technology spillovers from imports and linkages with multinational corporations (Park and Lippoldt, 2008; Motohashi and Yuan, 2010). Under such a premise, it is necessary to study the impact of environmental regulation on technological innovation.

On the one hand, environmental regulation has a negative effect on technological innovation. Petroni et al. (2019) argues that under high levels of environmental regulation, firms have to resort to production shutdowns, production cuts, and technological innovation. Firms have to take measures such as production shutdown and staff reduction, leading to a significant reduction in the resources that they have for technological innovation, which leads to slower product innovation and loss of competitiveness when competing with similar foreign products.

On the other hand, there is a positive effect of environmental regulation on technological innovation. Porter's hypothesis suggests that appropriate environmental regulation can promote technological innovation activities, generate "innovation compensation effects" to offset environmental costs, enhance firms' technological innovation capacity and productivity, and promote trade (Porter and Van der Linde, 1995). For voluntary environmental regulation, some scholars have tested Porter's hypothesis with ISO 14001 (Lim and Prakash, 2014; Bu et al., 2019). When compared with other types of environmental regulation, voluntary environmental regulation is the spontaneous behavior of firms, which are different from the mechanisms of traditional environmental regulation in promoting technological innovation. On the one hand, when

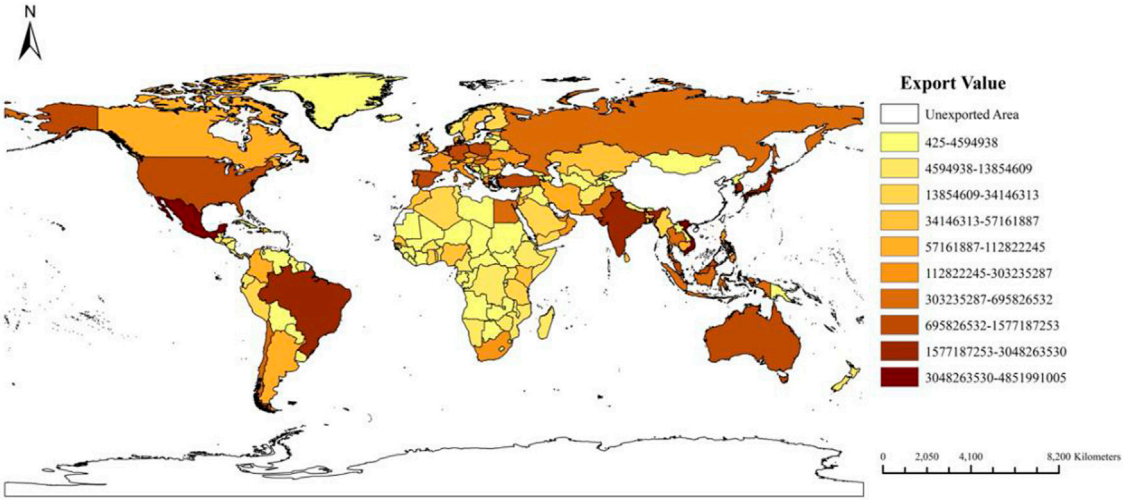

FIGURE 1
Global distribution of China's solar energy industry exports.

companies face mandatory environmental regulation, they tend to follow the incremental mode of technological transformation because technological innovation requires long periods of time, high investment, and high risk, i.e., they acquire pollution reduction facilities instead of technologically innovating to achieve an effective reduction of compliance costs in the short term (Wan et al., 2021). On the contrary, companies that voluntarily ascribe to the ISO 14001 standard will accelerate their technological innovation to meet or even exceed the environmental standards set by the government in order to obtain government recognition and thus receive government support such as access permits, tax incentives, subsidies, financial support, and land resources (Shu et al., 2016). In addition, Fombrun (1996) proposed the theory of "reputation wealth creation". He argues that organizations or companies with sufficient reserves of reputational capital have a unique advantage. If an enterprise carries out ISO 14001 certification and announces it to the public as a commitment to the quality of its products, the public will have a good perception of it if it can always fulfill the implied promises in the long-term operation process, and in the process of accumulating perceptions, the enterprise will build up a good reputation, which will enhance the international recognition and competitiveness of its products.

There is also a small group of scholars who argue that environmental regulation does not have a significant impact on technological innovation, i.e., the uncertainty hypothesis (Aiken et al., 2009).

Costantini and Crespi (2008) used a gravity model to explore the effects of national environmental regulation and technological innovation on energy technology exports and showed that environmental regulation and technological innovation have a significant positive effect on energy technology exports. If a country has strong environmental regulations, it becomes a net exporter of environmental technologies, thus confirming the Porter hypothesis. Costantini and Mazzanti (2010) further studied the impact of environmental policies on energy technology exports. The results showed that a lack of coordinated environmental policy mix may potentially have a negative effect on energy technology exports. Johnstone et al. (2010) used patent panel data of 25 OECD countries from 1978 to 2003 to examine the impact of environmental policies in the field of renewable energy on technological innovation. The results showed that public policy has a significant impact on the number of technology patent applications. When compared with other renewable energy sources, solar energy has always been innovative.

However, the aforementioned studies do not take into account the specific characteristics of the renewable energy industry and ignore the possible impact of the policy and market environment of the importing countries. Under the open economy conditions of economic globalization and accelerated regional economic integration, a country's environmental regulation not only has an impact on its own industry but also affects the trade patterns of other countries through trade and other factors' transnational flow behaviors. Based on this, Groba (2011) added importing country factors to his study and found that countries with stronger environmental regulations and more renewable energy policies export more solar technology–related products; countries that implemented renewable energy policies earlier had comparative advantages in renewable energy technology trade; in addition, the renewable energy policies of importing countries would also influence the level of policies of exporting countries.

3 Structural properties of world solar energy industry trade network

With the accelerated development of global energy structure transformation, China's solar energy product export markets have shown a trend of diversified development in recent years. In 2020, China's total export of solar energy products was about $44.2 billion,

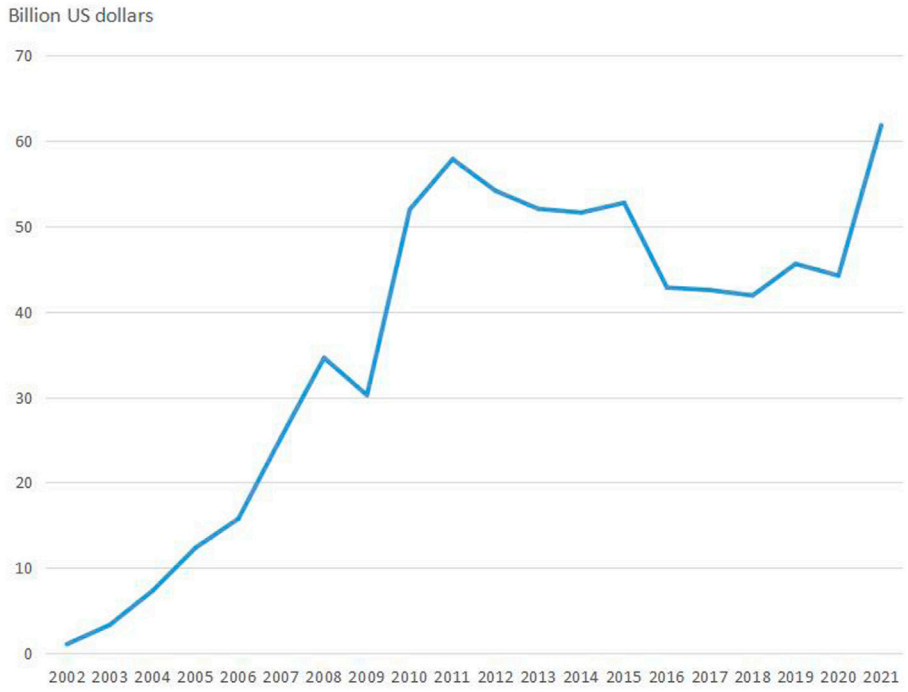

FIGURE 2
Export trends of China's solar energy industry from 2002 to 2021.

accounting for 44.4% of the world's total export of solar energy products. China exported solar energy products to 203 countries and regions in 2020 (Figure 1), and the top three destination countries were Vietnam, Mexico, and the Netherlands. The trade value of Vietnam's imports was about $4.8 billion, accounting for about 11% of the total value of China's solar energy product exports. Located in the sub-equatorial region, Vietnam has good solar resources. In particular, after the decision of Vietnam to issue an incentive mechanism for the development of solar power projects in 2017, the corresponding import volume of solar energy products had sharply increased.

From the perspective of regional markets, Southeast Asia, Latin America, and other emerging markets have signed the "Belt and Road" Initiative that is gradually replacing the EU and other traditional markets as the main market for China's solar exports. In 2020, China exported about $9.5 billion of solar energy products to the EU, accounting for 21.5% of the total value of China's solar energy product exports, while about $14.9 billion of solar energy products were exported to countries that have signed the Belt and Road Initiative, accounting for 33.6% of the total value of China's solar energy product exports. The gradual strengthening of countermeasures, such as anti-dumping and countervailing duties, and price restrictions by developed countries in Europe and the United States has, to a certain extent, led to the contraction of the European and American markets and also promoted China to seek a more diversified export market layout.

China's export trend of solar energy products from 2002 to 2021 is shown in Figure 2. In general, the scale of China's solar energy exports has been growing and it experienced a process from a rapid rise to a small decline to a shock rebound. Since 2002, with the rise of the global green energy concept and renewable energy industry, especially the linear growth of European photovoltaic demand, China's solar exports have begun to enter the first burst period. By 2011, the export rate of products produced by Chinese photovoltaic enterprises had gone up to 90% or more, of which Europe accounts for about 70% and the United States accounts for 10%. The domestic market development is extremely limited.

Due to the rapid decline of the photovoltaic market and the anti-dumping and countervailing duty investigations in the United States and the European Union, the export volume of solar energy products between China, the EU, and the US has decreased significantly since 2011. In 2017, the survey data of the US showed that the solar energy industry relies heavily on imports, leading to the slow development of the local solar energy industry. In order to address this problem, the United States enacted a law in 2018 to impose a 30% tariff on photovoltaic panels and modules imported from China on top of the existing tariff rate, with an annual increase of 5% in the next 4 years. From 2016 to 2018, exports continued to fall again due to shrinking overall market demand and the impact of trade war between China and the US.

China's major solar energy product export trading partners are gradually shifting from the traditional countries such as US, Italy, the Netherlands, and Germany to emerging market countries such as Singapore, India, South Korea, and Japan. In 2019, exports began to stop falling and rebounded, rising 8.9% year over year, mainly due to the rapid growth of exports to countries along the Belt and Road. In the long term, on the one hand, China's exports of solar energy products face diversified trade barriers. On the other hand, driven by renewable energy transition and green recovery policies of many countries, China's exports of the solar energy industry face

TABLE 1 Overview of variables.

Variable	Description	Source	Mean	Std. dev.	Min	Max
Lnexport	Exports of China's solar energy industry in log	UN Comtrade database	8.2151	3.3429	−9.2103	13.6249
lniso_d	ISO 14001 certification of the host country in log	ISO survey	6.4336	2.1110	0.0000	10.5855
lniso_o	ISO 14001 certification of China in log	ISO survey	10.7098	1.1771	7.9384	12.0325
iso_dis	Regulatory level gap between China and the host country	World Bank Development database and ISO survey	0.4902	0.4003	−1.3912	1.2021
lngdp	Gross domestic product of the host country in log	World Bank Development database	8.0802	1.6101	3.7575	12.2753
lnpop	Population of host country in log	World Bank Development database	17.2869	1.3944	14.0890	21.0454
cost	Trade cost calculated by the indirect method	World Bank Development database and UN Comtrade database	0.5323	0.0946	0.3415	1.0000
lninfra	Infrastructure construction index in log	World Bank Development database	3.9331	0.9107	−0.7209	5.8437
tariff	Import tariffs on machinery in the host country	World Integrated Trade Solution (WITS)	5.7914	4.5527	0.0000	27.8900
exrate	Nominal exchange rate between host country's currency and RMB	UNCTAD trains database	3.7410	4.4064	0.0003	21.5268

opportunities. Therefore, in this context, it is particularly important to study the relationship between China's solar energy industry exports and environmental regulation of importing countries.

4 Empirical approach

4.1 Data

We used the export data between China and 46 countries, covering product categories of the solar energy industry. The sample countries were the top 46 host countries for exports of China's solar energy industry in 2020, and these countries account for 86.3% of China's solar exports. We selected the solar energy industry trade over the period 2002–2020 because Harmonized Commodity Description and Coding System (HS) coding had been the new statistical caliber H2 from 2002, with no substantial changes in the commodities involved in the HS coding of the H2–H5 versions; we confine the period of study that began in 2002. Following Bai (2018), the export scale of the solar energy industry included the photovoltaic industry, which included HS code 854140 (electrical apparatus, photosensitive, such as photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes); HS code 841919 (heaters, instantaneous or storage water heaters, non-electric, other than instantaneous gas water heaters); HS code 732290 (other air heaters and hot-air distributors such as distributors which can also distribute fresh or conditioned air, and parts thereof, not electrically heated); and HS code 901380 (optical devices, appliances, and instruments). The HS code export data source is the UN Comtrade database, which is the most important source of bilateral trade data across countries, covering all the sectors of economy.

Table 1 provides an overview of the variables used in the study and some descriptive statistics.

4.2 Variables

4.2.1 Dependent variables

The empirical model relates China's solar energy industry exports to voluntary environmental regulation in importing countries, while controlling for a set of other explanatory variables. The dependent variable lnexport is measured as the solar energy industry's total export sales in log.

4.2.2 Focal independent variables

The main variable relates to voluntary environmental regulation. Voluntary environmental regulation is measured through three dependent variables: lniso_d, lniso_o, and iso_dis. The voluntary environmental regulation involved with a particular country-pair is captured by the ISO 14001 diffusion for both China and the host nation, which is measured in log. We also add iso_dis as a measure of the regulation level gap between China and the host countries in the model. Following Zhu et al. (2012), the development of voluntary environmental regulation is measured by the number of ISO 14001 certifications per $100 million of GDP, and the regulation level gap between China and the host country is measured by the difference in ISO 14001 certifications per $100 million of GDP between the two countries.

Voluntary environmental regulation emphasizes that enterprises should consciously supply environmental public goods and improve environmental performance according to their own conditions (Pan et al., 2020). As a representative of voluntary environmental regulation, ISO 14001 certification can guide the production activities of the enterprises at the organizational level and improve the management and environmental performances (Albertini, 2019). ISO 14001 requires certification companies to pursue continuous improvement in environmental performance with specific environmental goals and corresponding self-restraint mechanisms, such as standardized manufacturing processes, to reduce material, operational, and environmental management costs in the production process (Iatridis and Kesidou, 2018). Hence, the higher the ISO 14001 certification level of the host country, the stronger the sense of environmental protection, and it is more inclined to import renewable energy products. In addition, ISO 14001 certification, as a potential medium to help enterprises obtain the support of stakeholders, can release a reliable signal for enterprises to actively fulfill their social responsibilities and relieve the information asymmetry between foreign importers and certified export enterprises. The smaller gap in ISO 14001 certification levels between the two countries means the closer the environmental management level, the more helpful it is to accelerate the construction of a trust relationship, and ultimately improve the competitiveness and market share of export products in the host country.

4.2.3 Control variables

4.2.3.1 Gross domestic product (lngdp)

Gravity models suggest that trade is influenced by factors outside the traditional comparative advantage such as geographical distance, economic development, and other factors (Tinbergen, 1962; Blind et al., 2018). The larger the economy of the importing country, the greater is the demand for imported products, which is conducive to promoting product exports.

4.2.3.2 Population size (lnpop)

Previous literature on bilateral trade flows has considered the population of the importing countries as an influencing factor (e.g., Swann et al., 1996; Blind and Jungmittag, 2005). The more the population of the importing country, the larger is the potential market size, which is conducive for increasing trade.

4.2.3.3 Trade costs (cost)

There are two main methods to calculate the trade cost: direct method and indirect method. The limitation of the direct calculation method is that there are different forms of non-tariff barriers. Due to the different indicators and measures used, it is difficult to get a unified conclusion (Fang et al., 2010). Based on the study of Hong and Zhan (2021), this study measures the cost of trade by using the indirect method. Assuming that the bilateral trade cost is symmetrical and the share of the bilateral tradable goods is also equal, then the calculation formula of the trade cost is

$$\text{cost} = C_{ijt} = C_{jit} = 1 - \left[\frac{EX_{ijt}E_{jit}}{(GDP_{it} - EX_{it})\left(GDP_{jt} - EX_{jt}\right)\mathrm{s}^2}\right]^{\frac{1}{2\rho-2}}, \tag{1}$$

where EX_{ijt}, EX_{jit} represent the trade flow from China to its trading partners and from the trading partner countries to China, respectively. EX_{it}, EX_{jt} represent the total trade exports of China and the trading partner countries, respectively. GDP_{it}, GDP_{it} represent the total output of China and its trading partners, respectively. The share of tradable goods and alternative elasticity of the products are commonly used in literature (i.e., $s = 0.8$, $\rho = 8$). If bilateral trade increases relative to domestic trade, the cost of trade decreases.

4.2.3.4 Infrastructure construction (lninfra)

It is used to control the impact of the market trading environment on export trade flows. Based on the study of Clougherty and Grajek (2014), it was measured by the average of four items, namely, types of Internet users per 100 people, mobile cellular subscriptions, liner shipping–related indices, and airport boarding in a country.

4.2.3.5 Tariff (tariff)

For the importing countries, there are import tariffs on mechanical products, which include solar energy products. As one of the important factors affecting trade, tariff plays an important role in the development of foreign trade. The lower the import tariff, the larger is the volume of import trade.

4.2.3.6 Exchange rate (exrate)

This is expressed as the nominal exchange rate between the trading country's currency and RMB, adopted by the direct bid-price method. Changes in the exchange rates will have an impact on trade in the long term. When compared with other countries, when the exchange rates rose, RMB depreciated and exports increased.

4.3 Model specification

We examine the impact of voluntary environmental regulation on China's solar energy industry exports using panel regressions. The basic model specification can be expressed as follows:

$$lnexport_{it} = \alpha + \beta lniso\_d_{it} + \gamma lniso\_o_t + \vartheta control_{it} + \lambda_i + u_t + \varepsilon_{it}, \tag{1a}$$

$$lnexport_{it} = \alpha + \beta iso\_dis_{it} + \gamma lniso\_o_t + \vartheta control_{it} + \lambda_i + u_t + \varepsilon_{it}, \tag{2}$$

where i and t are subscripts representing the export destination country and year, respectively. $control_{it}$ is a vector of the control variables at the country level that have been shown to affect solar energy industry exports.

Accordingly, our baseline regression equation follows the prescriptions given by Clougherty and Grajek (2014) and Hong and Zhan (2021) concerning explicitly controlled trade–effect estimation:

First, we control the impact of any time-specific effects, e.g., world income trends in the data series with year dummies; employing time λ_i effects is a standard practice in empirical models of international trade. Second, we consider fixed country-pair specific effects that account for generating robust causal inferences. Our basic equation does not explicitly account for some trade drivers that do not vary over time, which include all observed (e.g., currency unions, colonial history, common language, and common border) and unobserved factors. These factors can be controlled for by means of country-pair specific fixed effects (FE) estimations (Baier and Bergstrand, 2007; Clougherty and Grajek, 2014).

TABLE 2 Test of multicollinearity.

Variable	(1) VIF lnexport1	(2) VIF lnexport1
lniso_d	4.64	
lniso_dis		1.22
lngdp	9.04	5.98
lnpop	5.49	5.82
lninfra	3.07	2.81
tariff	2.85	2.70
cost	1.57	
exrate	1.47	1.44

In short, country-pair fixed effects control for a large share of the possible sources of endogeneity by accounting for all observed and unobserved time-invariant factors, therefore it behooves us to undertake these estimations.

5 Empirical results and discussion

5.1 Benchmark regression results

The basic test results of the impact of voluntary environmental regulation on China's solar energy industry exports are shown in Table 3. Table 2 shows pre-estimation tests of multicollinearity, and the results show that the maximum value of the variance inflation factor (VIF) did not exceed 10, which can be considered to be no multicollinearity problem. In Table 3, columns (1) and (3) test the impact of ISO 14001 certification and show the estimation results by the method of OLS and bidirectional fixed effects for regression analysis, respectively. Columns (2) and (4) use OLS and bidirectional fixed effects to test the results of the ISO 14001 certification gap between China and the host countries on exports. The results show that the ISO 14001 certifications of China and the export destination countries both have a highly positive correlation with exports, and its regression coefficient is positive at a significance level of more than 5%, indicating that voluntary environmental regulation has significantly promoted the improvement of China's solar energy industry exports. Furthermore, convergence in voluntary environmental regulation between China and the host country will also promote export growth.

As far as the control variables are concerned, gross domestic product, population, and infrastructure construction all have positive impacts on exports, and trade costs have a negative relationship with exports. The results are consistent with the research conclusions of the previous paper (Anderson and van Wincoop, 2003; Clougherty and Grajek, 2014). We noticed that the impact of exchange rates is not obvious. In the context of the deep economic integration of various countries, the depreciation and appreciation of currencies, if not more than 10%, will have very little impact on the trade composition (Ye et al., 2006). We also find that the impact of tariffs on Chinese solar energy industry exports is small, in part because the tariffs used in this paper are for solar energy mechanical products rather than the average tariff level for all solar energy products. On the other hand, we believe that Chinese equipment, technology, management, raw materials, and accessories are the main competitive advantages in the solar energy industry (Liu and Shi, 2008), while tariff changes do not have a big impact on exports in the long term.

TABLE 3 Impact of voluntary environmental regulation on China's solar energy industry exports.

Variable	(1) OLS lnexport	(2) OLS lnexport	(3) FE lnexport	(4) FE lnexport
lniso_d	0.9243***		0.6545***	
	(0.0322)		(0.1424)	
lniso_dis		−0.5969**		−0.8083***
		(0.2566)		(0.3104)
lniso_o	1.2232***	1.7926***		
	(0.0577)	(0.0872)		
lngdp			1.0655***	1.3786***
			(0.3558)	(0.3702)
lnpop			2.3205**	3.0701***
			(1.1468)	(1.1741)
cost			−2.4769**	
			(0.9660)	
lninfra			0.2446	0.5190**
			(0.2547)	(0.2303)
tariff			0.0027	0.0028
			(0.0402)	(0.0406)
exrate			0.0688	0.0471
			(0.1211)	(0.1299)
Constant	−10.8317***	−10.6901***	−44.6351**	−57.8337***
	(0.5964)	(0.8867)	(19.1432)	(19.6527)
Control year	NO	NO	YES	YES
Control area	NO	NO	YES	YES
Observations	874	874	874	874
F-statistics	883.75	245.98		
R-squared	0.6699	0.3610	0.8617	0.8561

Robust standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

5.2 Robustness analysis

We further tested the stability of the effects of voluntary environmental regulation on China's solar energy industry exports, as

TABLE 4 Test of endogenous.

Variable	(1)	(2)	(3)	(4)
	2SLS	2SLS	SYS-GMM	SYS-GMM
	lnexport	lnexport	lnexport	lnexport
L.lnexport			0.4417***	0.5512***
			(0.0209)	(0.0100)
lniso_d	0.7570*		0.6420***	
	(0.3941)		(0.0829)	
lniso_dis		−3.5211***		−0.5776***
		(0.7886)		(0.0723)
lngdp	1.0182***	1.6528***	−0.0626	0.6909***
	(0.3514)	(0.3254)	(0.0837)	(0.1663)
lnpop	2.2522***	3.5474***	0.5730***	0.4479
	(0.7197)	(0.7161)	(0.1262)	(0.3009)
cost	−2.4994***		−3.2222***	
	(0.9603)		(1.0440)	
lninfra	0.2023	0.4859***	1.4359***	1.5911***
	(0.2200)	(0.1564)	(0.0676)	(0.1070)
tariff	0.0024	−0.0001	0.0159	0.0229
	(0.0302)	(0.0319)	(0.0138)	(0.0224)
exrate	0.0765	0.1228	−0.0009	0.0090
	(0.0805)	(0.0819)	(0.0232)	(0.0436)
Constant			−8.9124***	−12.0574**
			(2.1891)	(4.6871)
Cragg–Donald Wald F	76.57	229.66		
Sargan	1.0000	1.0000	1.0000	1.0000
AR(1)			0.0491	0.0389
AR(2)			0.3876	0.4781
Observations	874	874	828	828

Robust standard errors in parentheses***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

shown in Tables 4, 5. First, considering the possible reciprocal causal relationship between voluntary environmental regulation and exports, which affect the reliability of the regression results, we used the instrumental variable 2SLS and GMM methods to solve the possible endogenous problems. Considering that ISO 9001 is the earliest and most widely adopted international management system standard issued by ISO, many enterprises apply for ISO 14001 after passing ISO 9001 certification, so the diffusion rate of ISO 9001 certification in a country is usually highly positively correlated with the diffusion rate of ISO 14001 certification (Corbett and Kirsch, 2001). Table 4 shows that the results of the impact of the voluntary environmental regulation are consistent with the basic regression conclusions after considering endogenicity, where ISO 9001 adoption levels are used as instrumental variables for ISO 14001 variables. To rule out the concern of weak instrumental variable, we conducted the Stock–Yogo weak ID test. As the result shows, the Cragg–Donald Wald F-statistics are far beyond the critical value of the Stock–Yogo weak ID test (16.38), which clearly denies the weak instrumental variable concern and implies that our instrumental variable is not weak. The Sargan–Hansen test is a test of overidentifying restrictions, and the results show that the instruments are valid instruments. The *p*-values of AR (1) and AR (2) tests in Table 4 indicate that the residual sequence of the difference equation has only the first-order sequence correlation but no second-order sequence correlation, and the model passed the autocorrelation test. The Sargan statistics of the GMM model indicate that all of the instrumental variables are valid. The GMM model has passed the Arellano–Bond sequence correlation test and the Sargan test, so the estimation results of the systematic GMM are consistent and reliable.

TABLE 5 Test of robustness analysis.

Variable	(1)	(2)	(3)	(4)
	FE	FE	NNM	NNM
	lnexport_p	lnexport_p	lnexport	lnexport
lniso_d	0.5624***			
	(0.1986)			
lniso_dis		−1.2357**		
		(0.5999)		
lngdp	0.2147	0.5486		
	(0.5171)	(0.5363)		
lnpop	2.8206**	3.5353***		
	(1.3640)	(1.3185)		
cost	−1.7927			
	(1.2522)			
lninfra	0.9890**	1.2162***		
	(0.4059)	(0.3891)		
tariff	0.0919	0.0915		
	(0.0586)	(0.0594)		
exrate	0.2488*	0.2445*		
	(0.1420)	(0.1479)		
lniso_d_treated			2.8080***	
			(0.3657)	
lniso_dis_treated				−0.6928*
				(0.3772)
Control year	YES	YES		
Control area	YES	YES		
Constant	−51.5268**	−64.1849***	7.9356***	8.1462***
	(21.9501)	(21.3626)	(0.1154)	(0.1190)
Observations	874	874	874	874
R-squared	0.8117	0.8098	0.0633	0.0039

Robust standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

Second, the export of photovoltaic products is used as an alternative variable for solar energy industry exports. The regression results are shown in columns (1) and (2) of Table 5, and the research conclusions were basically unchanged. Third, considering the problem of missing variables, this study uses the matching method to test the benchmark regression results. We ranked samples according to the number of ISO14001 certifications, selected the top 10% of samples with larger number of certifications as the treatment sample group, and the other 90% were categorized as the control sample group, and set the dummy variable lniso_d_treated. We ranked the ISO14001 certification gap between China and host countries in the same way, selected the top 10% of samples with larger gap as the treatment sample group, and the other 90% were categorized as the control sample group, and dummy variable was set to lniso_dis_treated. The conclusions drawn after treatment matching are shown in columns (3) and (4) of Table 5, which indicate that the results of the benchmark regression are robust.

5.3 Analysis of heterogeneity

Table 6 includes the regression results of differences in impact of voluntary environmental regulation among countries with different degrees of economic development. Following the classification conducted by the World Bank's GNP standard in 2014, we divided the sample countries into 20 developed countries and 26 developing countries.

The estimated coefficient of voluntary environmental regulation is basically consistent with the results of the overall sample in the benchmark regression. Columns (1) and (2) of Table 6 show that the host countries' diffusion of ISO 14001 is conducive to China's solar energy industry exports, both in developed and developing countries. It means that the improvement of the environmental management of the host country enterprises will be conducive to promote the demand for renewable energy products. From the regression coefficient, the diffusion of ISO 14001 in developing countries has a more significant effect on promoting China's exports. Slightly different from the benchmark regression results, the coefficient of lniso_dis in the sample of exports from China to developing countries was positive and insignificant, as shown in column (4) of Table 6. It means that the convergence of voluntary regulation levels in China and developed countries has effectively promoted China's export of solar energy products to these countries, but the convergence with developing countries has no such effect.

5.4 Moderating effects

To examine the interaction effects between trade barriers and voluntary environmental regulation, we include multiplicative interaction terms between lniso_d, lniso_dis, and TBT. The variable lnTBT means that TBT notifications are measured in log, which is reported in WTO Integrated Trade Intelligence Portal Services. The coefficient of the interaction term lniso_d*lnTBT is negative and significant according to column (1) in Table 7. This means that the increased trade friction will significantly reduce the impact of host country's ISO 14001 diffusion on China's solar energy industry exports. However, we find the coefficient of the interaction term lniso_dis*lnTBT is not significant according to column (2) in Table 7, which means that an increase in TBT would not affect the impact of voluntary environmental regulatory convergence.

6 Discussion and concluding remarks

In our study, we have contributed two bodies of literature: the renewable energy industry trade and the relationship between environmental regulation and trade. With the strengthening of

TABLE 6 Developed countries vs. the developing countries.

Variables	(1) FE Developed lnexport	(2) FE Developing lnexport	(3) FE Developed lnexport	(4) FE Developing lnexport
lniso_d	0.3820**	0.4969**		
	(0.1552)	(0.2007)		
lniso_dis			−0.7702*	0.2480
			(0.4247)	(0.4770)
lngdp	1.2645**	1.0082**	2.3744***	1.1520***
	(0.6272)	(0.4115)	(0.7106)	(0.4307)
lnpop	−4.9792**	2.6115**	−6.6048***	2.9195**
	(2.2331)	(1.1351)	(2.4734)	(1.1748)
cost	−21.4959***	−1.5243		
	(2.6819)	(0.9544)		
lninfra	0.6729*	0.4895*	0.6333*	0.5922**
	(0.3507)	(0.2815)	(0.3607)	(0.2686)
tariff	−0.5075***	0.0270	−0.6089***	0.0323
	(0.1882)	(0.0352)	(0.1907)	(0.0354)
exrate	0.2993***	−0.2201	0.0867	−0.2211
	(0.0999)	(0.2175)	(0.1010)	(0.2257)
Constant	86.8443**	−48.9624**	98.5518***	−54.1125***
	(34.4444)	(19.1831)	(38.0248)	(20.0134)
Control year	YES	YES	YES	YES
Control area	YES	YES	YES	YES
Observations	380	494	380	494
R-squared	0.8879	0.8715	0.8704	0.8682

Robust standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

environmental protection, the renewable energy industry trade has become a strategic choice for many countries to ensure energy security. China is rich in solar energy resources and has huge export potential. We analyze China's energy industry trade networks, further analyze the effects of voluntary environmental regulation on the solar energy industry trade in the discussion, and use empirical conclusions to fill the gaps in the literature.

This study argues that the voluntary environmental regulation represented by ISO 14001 has an important impact on the solar energy trade. To support our argument, we investigated three different effects of the ISO 14001 standard on the trade in the solar energy industry: the demand effect in the importing country, information effect, and the common language effect.

The solar energy industry, as a green industry, is more attractive to foreign buyers who are more environmentally conscious, and ISO 14001 certifications can increase the demand for domestic products from those foreign buyers by transforming the "green" trustworthy attributes of the products into search attributes (Chen and Pin, 2017).

Cultural, institutional, and economic distances between countries give rise to substantial uncertainty and asymmetric information between the transacting parties. Especially in some developing countries, due to the asymmetry of information and out of perception, foreign buyers often think that the products of enterprises in these countries do not have good quality. This certainly imposes some additional responsibilities on the company (Hudson and Jones, 2003; Clougherty and Grajek, 2008; Marano et al., 2017). ISO 14001 certification can reduce the asymmetry and opacity of information. In addition, the adoption of some kind of open standard in the importing

TABLE 7 Test of moderating effect.

Variable	(1) FE lnexport	(2) FE lnexport
lniso_d	0.8295***	
	(0.1525)	
lniso_dis		−1.8883**
		(0.7641)
lniso_d*lnTBT	−0.0789***	
	(0.0239)	
lniso_dis*lnTBT		0.2403
		(0.1615)
Constant	−35.4966*	−54.6836***
	(18.5216)	(19.5594)
Control variables	YES	YES
Control year	YES	YES
Control area	YES	YES
Observations	874	874
R-squared	0.8649	0.8567

country can also make accessing local information easier for foreign companies, such as conditions that have to be met to sell their products in that country's market according to consumer preferences, thus creating more trade opportunities.

ISO 14001 certification on both sides of the trade country and proliferation at the same time can also reduce the cost of communication between enterprises in both countries. Blind (2001) pointed out that consistent technical knowledge between the two countries fundamentally improves the efficiency of communication and facilitates cross-border trade, and standards must be adopted in both the importing and exporting countries to establish the characteristics of a common language. This is because when both importing and exporting firms adopt the same standard, they also agree on certain aspects of production operations, making it easier to trade.

We use data on exports between China and 46 countries, covering product categories in the solar energy industry, using the number of ISO 14001 certifications as a proxy variable for voluntary environmental regulation. The impact of voluntary environmental regulation on solar energy industry exports is verified for the period 2002–2020. The findings support the positive impact of both Chinese and the host country voluntary environmental regulation on the exports of the Chinese solar energy industry. This empirical result is consistent with the conclusion of some previous studies (e.g., Nishitani, 2009; Martincus et al., 2010), which supports that voluntary environmental regulation is conducive to expand the scale of enterprise exports. The estimation results indicate that the ISO 14001 certification gap between China and host countries has a negative impact on exports. Voluntary environmental regulation not only reflects its strong motivation to achieve long-term improvements in environmental performance through technological innovation (Camisón, 2010) but also means that enterprises have the objective conditions required for technological innovation. The smaller the gap in certification levels between the bilateral countries means an equal willingness and technology to fulfill environmental responsibilities, and the more helpful it is to accelerate the construction of a trust relationship (Testa et al., 2018), thus boosting trade growth.

Among countries comparing different levels of economic development, raising the level of voluntary environmental oversight in developing countries as host countries is more important than in developed countries to promote China's solar energy exports. This is mainly due to different environmental regulation levels in different countries. Developed countries represented by the EU have always focused on the improvement of enterprise environmental management. Before the international organization for standardization proposed ISO 14001 certification, the European Commission has been implementing the Ecological Management and Audit System (EMAS), which proposes higher requirements than the ISO 14001 certification, such as holding legitimacy signed by the competent authority, making direct commitment to continuously improve environmental performance, increasing system transparency, and ensuring the effective participation of employees (Marrucci and Daddi, 2022). Therefore, in this context, the impact of the diffusion of ISO 14001 certification on the EU and other developed countries in improving the environmental performance requirements is relatively weakened, and the demand effect of renewable energy products is also weakened. Based on the aforementioned discussion, the diffusion of ISO 14001 certification has a stronger driving effect on China's export of solar energy products to developed countries than to developing countries.

The experiment further demonstrates that the convergence of China's level of voluntary regulation with developed countries effectively promotes China's exports of solar energy products to these countries, but the convergence with developing countries does not have this effect. The reason is not difficult to explain as ISO 14001 certification has the characteristics of network effects (Wang, 2015). The level of voluntary environmental certification of enterprises in developed countries with market dominance is relatively higher than China. The smaller the gap with China, the more obvious the certification information effect is, and the greater the export-pulling effect will be. By contrast, the diffusion of ISO 14001 in developing countries is relatively small, and the information network effect of certification is not obvious. Moreover, the developed countries themselves have a higher level of voluntary environmental regulation. As a developing country, China has improved the level of voluntary environmental supervision and integrated with developed countries, promoting green innovation to some extent, thus generating greater export advantages (Xiao, 2022).

The impact of trade barriers has also been looked at in our study. The increase in trade barriers will undoubtedly reduce the trade volume of both countries (Chandra, 2016). In previous studies, trade barriers have had an important impact on the export of renewable

energy products (Jha, 2009; Groba, 2014). The situation of foreign trade protectionism faced by the Chinese solar energy industry shows an increasing trend (Wang et al., 2022). In March 2022, India issued a final anti-dumping ruling on solar and fluorine-coated backsheets imported from China and decided to impose anti-dumping duties on the products in question for 5 years. In 2022, the United States imposed emergency import restrictions on PV modules, extending additional tariffs on imports from China for 4 years. Similarly, our study found that trade barriers play an important intermediary role in the export of solar energy products from China. An increase in TBT in both countries would diminish the positive impact of voluntary environmental regulation in host countries on China's solar energy exports, while an increase in TBT would not affect the impact of voluntary environmental regulatory convergence. This is a signal that even as trade frictions increase, convergence in voluntary environmental regulation between the two countries will still give a strong boost to China's solar energy exports.

Our findings also have policy implications. First, some scholars believe that there are differences in voluntary environmental regulation levels among different countries, which form green trade barriers and thus inhibit international trade (Barrett, 1994; Essaji, 2008). The conclusion of our study rejected this view. On the one hand, countries with strict voluntary environmental regulations have greater demand for solar energy products; on the other hand, ISO 14001 certification improves the accuracy and transparency of information, creating obvious export opportunities for foreign companies and reducing the cost of obtaining information about the environment of the importing country (Swann et al., 1996). As a result, the diffusion of ISO 14001 will generally promote the export of the solar energy industry through the demand and information effects, which means that in order to promote the trade of renewable energy products, both exporting and importing countries should strengthen the formulation and diffusion of voluntary environmental regulation.

Second, in recent years, the global spread of ISO 14001 certification, especially rapidly in developing countries, has helped in narrowing the gap in voluntary environmental regulation among countries. The signal display function derived from the certification produces the common language effect of environmental management in trade (Bénézech et al., 2001; Grajek, 2004), which is particularly important for China's exports to developed countries with a mature market environment and stricter environmental regulations. In addition, the adoption of ISO 14001 may qualify firms to establish a cooperative relationship with multinational firms, which often has requirements for a green supply chain.

Third, as a high-tech industry, the solar energy industry has attracted the attention of many countries. In order to promote the development of domestic photovoltaic enterprises, trade protectionism is rising and trade frictions occur frequently Karp and Stevenson, 2012). Therefore, solar energy product exporters should strengthen the overseas trade cooperation and broaden the diversified development of export channels of photovoltaic products.

Finally, despite the numerous issues addressed in this study, there are some limitations which may be considered for research directions in the future. First, our study uses data from a wide set of countries across which the quality of certification-granting procedures and the effective implementation of the standards by firms may substantially differ (Christmann and Taylor, 2006). The study also fails to consider solar energy product exports from other countries except China within the time period. If these limitations can be overcome, it will bring further understanding to the research. However, even though there are different research dimensions, the study has limited its estimation to a macro-country perspective. Future studies can consider it at the enterprise micro level, and more new findings may be captured to explore the impact of voluntary environmental regulation on the export performance of the solar energy industry.

Despite the aforementioned limitations, we believe that the robustness of our results and their consistency with the conceptual underpinnings make an important contribution to the literature.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization: YS and HS; methodology: JL; software: YS; validation and formal analysis: TP. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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