**Do clean energy duties generate employment benefits?**

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*Accepted for publication in Renewable and Sustainable Energy Reviews, 2022*

***Abstract***

Renewable energy (RE) trade disputes have been rising in response to certain green industrial policies, i.e., policy mechanisms used to develop domestic RE industries and accrue associated local economic benefits. Since 2011, countries have been increasingly filing trade litigations to counter the use of green industrial policies by their trading partners so that they can expand RE industry competitiveness and the associated manufacturing jobs within their own countries. However, in the absence of systematic studies on the impacts of RE trade duties, evidence regarding their success in achieving these economic goals remains limited. We assess the effectiveness of RE trade duties in supporting employment, especially in manufacturing, by first reviewing the literature on the motivations behind trade duties, and then examining the case of trade duties imposed by the US on the imports of solar and wind energy components from China between 2011 and 2019. Although several factors may drive employment, we find no evidence of increase in jobs in solar and wind manufacturing in the years after the trade duties were imposed. Meanwhile, downstream jobs in installation, operation and maintenance continued to grow, corresponding to increases in annual installation of solar and wind capacity in the US, driven by policy incentives and the declining costs of solar and wind technologies. Overall, our case study highlights the broader implication that trade duties alone are unlikely to promote local manufacturing industries and countries would benefit from other well-designed policies.

**Highlights:**

- Renewable energy (RE) related trade disputes rising but studies examining effectiveness of trade duties limited.
- Literature on the goals behind trade duties on RE components reviewed.
- A framework developed to assess the relationship between RE trade duties and manufacturing employment.
- Framework applied to examine the case of trade duties by the US on the imports of solar and wind energy components from China.
- Trade duties not an effective policy to develop local RE industries; other well-designed policies required to increase local RE manufacturing jobs.

**Keywords**: green industrial policy, trade duty, trade dispute, anti-dumping, US-China relationship, renewable energy, manufacturing

**Word count:** 7420

**Abbreviations:**

AB – Appellate Body

ADD – Anti-dumping duty

CASM - Coalition of American Solar Manufacturing

CVD – Counter-veiling duty

DOC – Department of Commerce

EU – European Union

GATT - General Agreement on Tariffs and Trade

GHG – Greenhouse gas

GW – Gigawatt

ITC – Investment tax credit

LCR – Local content requirement

O&M – Operations and maintenance

PTC – Production tax credit

PV – Photovoltaic

RE – Renewable energy

SCM - Subsidies and Countervailing Measures

TRIM - Trade-Related Investment Measures

US – United States

USITC – United States International Trade Commission

USTR – Office of the United States Trade Representative

WTO – World Trade Organization

WTTC - Wind Tower Trade Coalition

## *1 Introduction*

The rapid global technology improvements and policy-induced incentives for renewable energy (RE) technologies have created opportunities for countries worldwide to simultaneously pursue climate, energy, and economy goals. Deployment of RE technologies, an important pathway for climate mitigation, has grown rapidly in the last decade. Between 2010 and 2019, the global installed capacity of solar technologies increased by 14.5 times (from 40.3 GW to 587.1 GW) and for wind technologies increased by 3.5 times (from 177.8 GW to 622.3 GW) [1]. With rising deployment, the economic benefits of developing RE industries are also growing. Between 2012 and 2019, jobs associated with solar technologies increased from 1.36 million to 3.75 million, and wind technologies increased from 0.75 million to 1.17 million [2]. RE jobs are expected to grow substantively in the coming decades. The International Renewable Energy Agency (IRENA) projects that if by 2050 RE meets two-thirds of the final energy supply, RE jobs would increase to 42 million jobs with solar technologies accounting for around half of these jobs [3].

The rapid global growth of RE industries has also led to tensions among countries as they compete with each other to maximize the local economic benefits of industry development. On the one hand, local RE deployment can help countries to meet their climate and energy goals, and also obtain local economic benefits such as the creation of downstream jobs in solar and wind installation and maintenance [4,5,6]. Such jobs are attractive as they are expected to be among the fastest growing jobs in the coming decades [3,7]. On the other hand, tensions can develop among countries as they try to expand local RE manufacturing jobs, either to protect existing industries given the recent manufacturing shifts to China, or to spur new industries especially in developing countries [8]. Governments want to localize RE manufacturing as much as possible in order to improve the competitiveness of their domestic RE industries, expand manufacturing jobs, and reduce dependence on foreign imports to meet their energy needs [9-11]. In this context, governments have been using green industrial policies to develop domestic RE industries and maximize the local economic benefits associated with their growth [8,12–19]. Examples of such green industrial policies include local content requirements (LCR), financial subsidies such as low-interest loans, grants, rebates or tax credits to firms. [13,16,17,20].

The growing use of certain green industrial policies—such as LCR or financial subsidies for setting up manufacturing—has brought on an increase in RE trade disputes [21–23]. While the World Trade Organization (WTO) is one of the most commonly used forums to raise RE-related trade disputes, countries have also taken unilateral action where they respond to the cases filed by domestic firms by imposing tariffs on foreign firms [23][1]. Countries are increasingly filing litigations against their trading partners to protect, maintain, and expand their own RE industry competitiveness and manufacturing jobs. For example, in 2012, *EU-ProSun* – a group of over 20 solar manufacturing firms in the European Union (EU) – complained against the dumping of Chinese solar panels, claiming that the dumping of cheap foreign imports threatened 25,000 industrial jobs in the EU [24]. Another example is that of the module-manufacturing firm *Suniva's* case against the dumping of foreign solar cells and modules into the United States (US) in 2017, where president of the firm *SolarWorld Americas* remarked that their firm was joining this complaint because "(w)e must take a stand in favor of preserving intellectual property, production know-how and US manufacturing jobs…" [25].

The rise in RE trade disputes has led to an emerging body of academic literature that has examined the role of different political and industrial actors involved in the disputes, their motivations, and perceptions of the trade duties [26-28]. This literature highlights that a firm's interests are best determined by its position in the global value chain of the RE industry, instead of its nationality.

[1] Generally, two kinds of trade tariffs are imposed in unilateral cases: i) countervailing duties (CVD) i.e., the duties that are imposed by a country on foreign imports that are cheaper than domestic products on account of the subsidies provided by foreign governments, and ii) anti-dumping duties (ADD) i.e., the duties that are imposed on foreign imports that are sold at less than their fair value in the domestic market.

In both US-China and EU-China solar dispute cases, the trade litigations filed by the US and EU based solar cell and module manufacturers against Chinese imports were opposed by domestic upstream firms who relied on exports (e.g., manufacturers of raw materials and solar manufacturing equipment) and downstream firms who relied on imports (e.g., project developers engaged in solar installations or deployment). Given their reliance on the Chinese market, these firms argued that trade duties would harm their business and hamper the overall growth of the domestic solar industry [24, 27]. Extant studies on the perceptions and reactions to RE trade duties also suggest different impacts of trade duties based on the firm's position in the RE global value chain, where manufacturers that face direct competition from cheap foreign imports in the duty-imposing country expect to gain from the imposition of trade duties, while installers are likely to lose out. However, in the absence of systematic studies on the impact of RE trade duties, there is limited evidence on the effectiveness of RE disputes on enabling green industry development, increasing jobs, or ensuring competitiveness. This is a crucial research gap given the growing interest in localizing RE manufacturing by countries worldwide and an associated rise in RE trade disputes.

In this paper, we address this gap by assessing the effectiveness of RE trade duties in achieving their stated goals, in particular related to employment generation. We study the case of trade duties imposed by the US on the imports of solar and wind energy components from China and examine the effectiveness of these duties on economic goals (measured through employment in manufacturing, installations, operation and maintenance) and climate change mitigation goals (measured through RE deployment). We review the multi-disciplinary literature examining the motivation and impacts of these trade duties and develop a framework to analyze whether and how trade duties can shape countries' goals of advancing local RE employment, particularly manufacturing jobs. We then use this framework in the context of solar- and wind- related trade duties imposed by the US on China, one of the most prominent trade disputes in the renewable energy industry in the last decade. While we recognize that several factors may drive employment, we find no evidence that the duties increased local solar or wind manufacturing jobs in the US. But due to the declining global costs of solar and wind technologies, annual installation of solar and wind capacity in the US continued to increase at rates similar to the global trends. This contributed to the growth of downstream jobs in installation and maintenance which contributed to the overall growth of solar and wind jobs in the US.

The rest of this paper is structured as follows. In section 2, we review the literature on green industrial policies and how it relates to RE trade disputes. We also present the framework of this paper. In section 3, we explain the methodology used to examine the effectiveness of RE trade duties in supporting employment. We present our results and discuss our findings in section 4. Finally, we present the conclusions in section 5.

## *2 Literature review and research framework*

In this section, we first review the relationship between green industrial policy and trade duties, noting why trade duties emerge in different country contexts (2.1). We then discuss the existing literature on the effectiveness of trade duties (2.2). We finally present our research framework (2.3).

### *2.1 Green industrial policy and trade disputes*

Governments have been actively pursuing policies that promote green industries, arguably with the goal of maximizing the associated local economic benefits. Scholars classify the policies that involve government support for developing domestic green industries as green industrial policies because their motivation and design is similar to the industrial policies that have played an important role in developing a wide range of industries worldwide – such as biotechnology or the iPhone [12,18]. Green industrial policies for RE include financial subsidies (e.g. low-interest loans, grants, rebates or tax credits to firms to scale up manufacturing) as well as targeted incentives for research and development, manufacturing or deployment [13,16,20]. To accelerate local green industry development and achieve economic objectives such as job creation, many governments follow the strategy where the provision of incentives is contingent upon the use of domestically manufactured equipment (i.e., local content requirement). Examples include LCR for solar modules purchased in auctions under the National Solar Mission in India [17,29] and LCR for solar PV and wind turbines under the Renewable Energy Independent Power Producer Procurement Program in South Africa [30].

Green industrial policy mechanisms have become increasingly popular as they allow governments to associate renewable energy deployment with local economic development. Emerging research shows that renewable energy policies receive greater public and political support when they are aligned with local economic benefits such as job creation and domestic industry competitiveness [11,15,31,32]. This evidence also suggests that governments can be motivated to adopt more ambitious climate policies if they recognize the economic benefits of pursuing those policies.

However, with the growth of certain green industrial policies, instances of trade litigations aimed at discouraging their use or countering their impact on RE industries are also rising [21–23]. Although green industrial policies are framed around local competitiveness, some of these policies, particularly those aimed at boosting RE manufacturing, may be constrained by domestic and international trade laws (see a review in Table 1). Countries can file litigations against their trading partners on grounds that the subsidies and protectionist measures that are pursued as part of green industrial policies go against the principles of free trade. Some green industrial policies are under illegal under the WTO rules and can be challenged at the WTO. Trade litigations can also be investigated by governments on their own if a domestic firm files a complaint against the use of certain green industrial policies by a trading partner [23]. One of the commonly disputed green industrial policy at the WTO is the requirement of using locally manufactured technology (i.e., LCR) for meeting RE deployment targets as it is prohibited as per the WTO rules. Other green industrial policies such as feed-in-tariffs that are not prohibited under the WTO rules on their own can also be challenged if they are pursued in conjunction with LCR. For example, in 2011, Japan filed a complaint against Canada at the WTO as Ontario state's feed-in-tariff required at least 60% of the solar components, and 50% of the wind components to be sourced from Ontario [23]. WTO found that Canada was in violation of the WTO rules because of the LCR provisions and asked Canada to comply with the international trade laws. In unilateral trade disputes in the solar industry, a majority of trade litigations are related to the provision of subsidies, tax incentives, and other assistance for manufacturing, resulting in counter-veiling and anti-dumping duties getting imposed on solar components such as cells, modules, and solar-grade polysilicon [27]. The wind sector is another major sector with trade disputes over components such as blades, gearbox, turbines etc. [22].

**Table 1:** This table illustrates the types of green industrial policies used to develop RE manufacturing that are commonly litigated at domestic and international trade forums. Prepared by authors based on [12,13,21].

| Green industrial policies for RE manufacturing | | Legality according to WTO rules | | Reaction from other countries and consequent trade dispute |
|---|---|---|---|---|
| Policy type | Example | Status | Applicable trade law | Trade dispute |
| Local Content Requirement or LCR (Requiring use of locally manufactured technology) | *National Solar Mission* (India)<br><br>*Green Ontario*, (Canada) | Prohibited | WTO-TRIMs*, WTO-SCM** | In 2013, US initiated a case against India as its solar mission included LCR requirements for solar cells and modules. India lost the case in 2016 as its measures were found to be inconsistent by the WTO under the TRIMs agreement and GATT rules, and India agreed to comply with the trade laws.<br><br>In 2010, Japan disputed Canada's 'Green Ontario' program as this feed-in-tariff program had an LCR provision. In 2013, the Appellate Body of WTO ruled that the LCR provision violated the TRIMs agreement, and Article III of GATT***, and was asked to comply with international trade laws |
| Subsidies and incentives for manufacturing such as direct capital subsidy, rebate, favorable loan, financial and tax incentives | Commonly used policies to develop local RE manufacturing | Prohibited if subsidies are linked to LCR, exports, or if subsidies are found to have "adverse impacts to the interests" of other WTO members<br><br>Subsidies permissible under WTO can be challenged by countries unilaterally at their domestic courts | WTO-SCM** | In 2012, an association of solar manufacturers in the US complained against the subsidies and 'dumping' of low-cost solar cells and modules from China in the US. The US International Trade Commission ruled that the imports from China are subsidized and sold at less than fair value in the US and imposed anti-dumping (ADD) and counter-veiling duties (CVD) on solar cells and module imports from China. The inquiry included four categories – subsidies, tax incentives, custom duties, and export credit assistance. The scope of the solar case was expanded in 2014 and again resulted in ADD and CVD imposed on Chinese imports.<br><br>In 2012, investigation against solar cells and wafers launched against China initiated by complaint from an ad-hoc industry group called Prosun. A minimum price undertaking was reached in 2013 which put a price floor and volume limit on imports from China. The European Union lifted the anti-dumping and anti-subsidy trade measures on the imported Chinese solar panels in 2018. |

*WTO-TRIMs is the WTO agreement on Trade-Related Investment Measures (TRIMs) which restricts measures such as domestic content requirement and trade balancing.
**WTO-SCM is the WTO agreement on Subsidies and Countervailing Measures (SCM) is concerned with issues related to provision of subsidies to industries, and the use of counter-veiling duties by member countries.
*** Article III of GATT discourages member countries to discriminate between imports, and similar products produced domestically.

### *2.2 Trade duties, climate change mitigation goals, and economic development goals*

The emergence of trade disputes in RE industries has led to a growing body of literature that examines the role of different political and industrial actors involved in these disputes and how they reacted to, or perceived, the trade duties [26-28]. However, there is limited evidence regarding the impact of these trade duties on achieving their stated economic goals of improving competitiveness and expanding manufacturing jobs in RE industries in the duty-imposing countries.

Existing research finds clear differences in the reactions and perceptions of trade duties among the manufacturers and installers of RE technologies. Given the globally dispersed nature of RE technologies like solar, not all firms in the duty-imposing country anticipate benefits from the imposition of trade duties. This was observed in the US-China and EU-China solar disputes where trade duties were opposed by the upstream firms that relied on the Chinese market for exports (e.g., manufacturers of raw materials and solar manufacturing equipment) and downstream firms that relied on the Chinese markets for imports (e.g., project developers engaged in solar installations or deployment) [26,28]. Upstream firms exported manufacturing equipment that was used by Chinese manufacturers to produce components like cells and modules, while the installation firms imported these cells and modules as their prices were cheaper than the domestically produced cells and modules. In both cases, trade duties were mainly supported by domestic solar cells and module manufacturing firms as they claimed that the Chinese manufacturing firms were hampering their growth. These firms argued that the Chinese firms were able to sell solar cells and modules at much cheaper rates because of the unfair subsidies and other such assistance that they received as part the policies enacted in China [24,27]. This highlights that a firm's interests in RE trade litigations are dictated by its position in the global value chain of the RE industry, rather than its nationality [28]. These differences in perceptions also suggest that the impact of trade duties among the different manufacturing and installation firms in the duty-imposing countries is likely to be opposite. While trade duties are expected to fulfil their objective of supporting domestic RE manufacturing firms that face direct competition from cheap foreign imports, they are also likely to depress the growth of RE installation by increasing the price of imported RE components or by compelling the domestic installation firms to use the more expensive domestic components [33].

Evidence regarding the actual impact of RE trade duties, particularly on meeting their stated economic goals of expanding manufacturing jobs, remains limited and uncertain. For the case of the US-China solar disputes, Hughes and Meckling [27] found that the trade duties possibly helped some US module manufacturers as the firm *SolarWorld* created 200-900 full time jobs in 2015 and one 200 MW manufacturing unit came up in the US state of Michigan. Some studies have looked into the RE trading patterns of duty-imposing countries to assess the impact of trade duties. They found that in the US, trade duties led to instances of trade diversion. After the US imposed anti-dumping and counter-veiling duties on China, the import of Chinese solar panels and modules declined and this decline was partly compensated by imports from Malaysia and Taiwan [26]. However, it was Chinese firms that moved their operations outside China after trade duties were imposed [34]. This limited evidence suggests that trade duties did not boost domestic solar manufacturing jobs in the US. Instead, the US diverted its import reliance for solar cells and modules to other countries.

As countries try to manage multiple goals around climate, energy, and economy, cases of trade disputes in RE industries are rising. The limited academic literature on the economic effects of trade duties suggests differences based on the firm's position in the global value chain, i.e., while manufacturers are generally expected to gain from the imposition of trade duties, installers are likely to lose out. The negative effects on installation firms can also slow down the pace of RE installations which implies that trade duties can have unintended negative consequences on the climate goals of the duty-imposing country. However, these effects of trade duties have not been studied systematically. In this paper, we address this gap by developing a qualitative case study to assess the effectiveness of trade duties in meeting the employment goals in the duty-imposing country.

### *2.3 Research Framework*

Given the limited academic literature on the impacts of trade duties, this paper assesses whether trade duties met the local economic goals of job creation. Building on our review of prior literature, we develop the following framework to conceptualize the relationship between trade duties, local green industry development, and climate change mitigation action in the duty-imposing country (Figure 1). We describe this framework in more detail in the following.

Green industrial policies are designed to meet the climate, energy, and economic goals in that country [12,18]. But given that RE industries are part of global value chains, the impacts on domestic jobs and competitiveness are related to green industrial policies implemented domestically as well as internationally [8]. Understanding the interplay of domestic and international green industrial policies is essential to assess the effectiveness of trade duties on the green industry goals of the duty-imposing country.

Domestic jobs, manufacturing, and deployment can depend on domestic green industrial policies that shape the demand for, and supply of, RE technologies. But this demand can also be met through cheap foreign imports that have become available because of international green industrial policies (i.e., the green industrial policies in other countries) designed to spur low-cost manufacturing, to expand RE industries, and to generate exports [15,18,20,26]. These international green industrial policies can create tensions when, because of the reliance on foreign imports, a country is unable to meet its domestic green industrial policy goals, such as developing local RE industries or creating domestic manufacturing jobs.

To offset such adverse impacts of certain international green industrial policies, countries have raised trade disputes and imposed trade tariffs (summarized in Table 1). Countries expect that by imposing such trade tariffs on their international trading partners, they can increase domestic RE manufacturing and employment.

However, as RE industries are part of global value chains, trade duties designed to limit low-cost imports may also affect local installations given the potential differences in costs of domestic and imported RE components. Duties on imported RE technologies can also impact the price of renewable energy within that country by increasing the price of imported RE components, or by compelling domestic installers to use the more expensive domestic components [33].

To address the research questions posed in this paper, we examine the effectiveness of imposing trade duties to counter some of the green industrial policies in an international location impact economic goals (measured through employment) and domestic climate goals (measured through RE deployment) of the duty-imposing country. As the aim of trade duties is to develop or protect the local green industry within the duty-imposing country, the unit of analysis in this paper is the duty-imposing country.

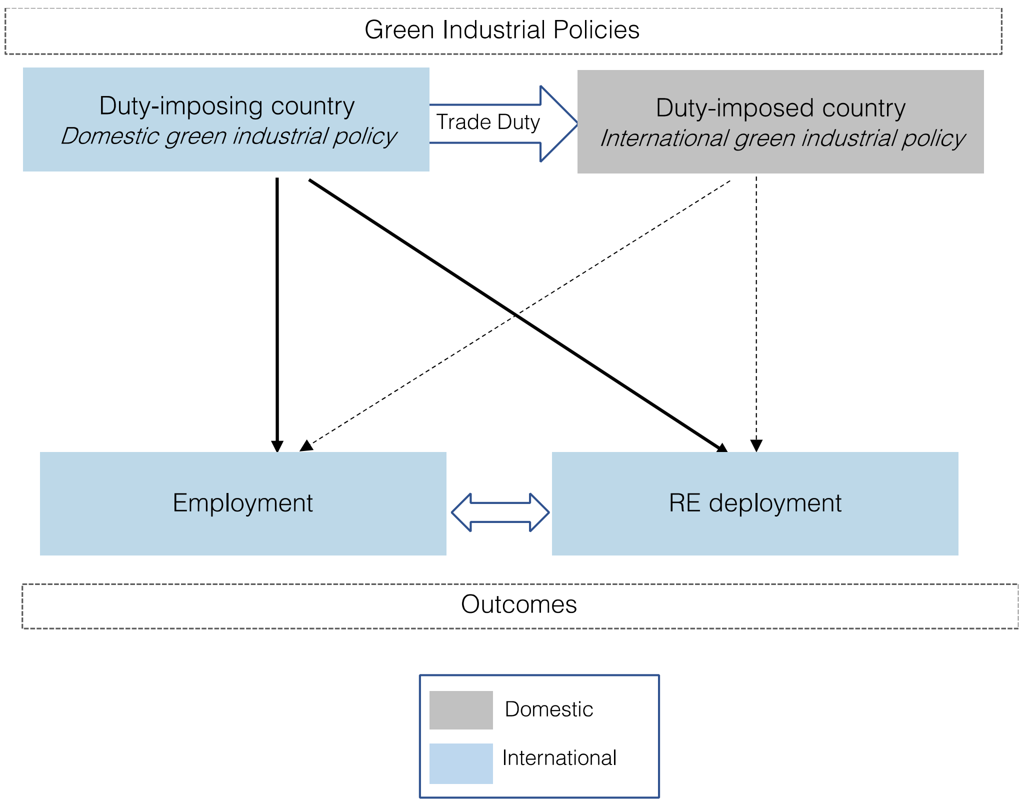


**Figure 1:** Conceptual framework to examine how trade duties imposed by a country on its international trading partner country help attain economic development goals (through domestic RE employment in manufacturing and in operations, maintenance or installation) and climate change mitigation goals (through RE deployment). The RE employment and deployment (marked by solid black arrows) in a country while related, are determined by its domestic green industrial policy. Low-cost RE imports available because of green industrial policies in other countries can also fulfil its domestic demand thus impacting both domestic RE employment and deployment (marked by dashed black arrows) in that country. As availability of cheap foreign imports makes it difficult for a country to develop its domestic RE industries and create manufacturing jobs, countries impose trade duties on their trading partners in order to offset these adverse impacts of their international green industrial policies. The total impacts of these trade duties depend on the domestic and international green industrial policies of the duty-imposing, and duty-imposed countries respectively.

### *3 Methods and materials*

To study the effectiveness of trade duties, we examined how the trends in achieving the economic goals (measured in employment), and climate change goals (measured with deployment of RE technologies) changed in the duty-imposing country before and after it imposed trade duties on foreign imports.

We studied the cases of the US imposing anti-dumping and counter-veiling duties on the import of solar and wind components from China. We focused on the US-China trade disputes for three reasons. *One*, the US and China are among the largest solar and wind markets. As of 2019, China had the highest installed solar capacity in the world at 205 GW, followed by the US at 62 GW. Similar for wind energy, China had the highest installed capacity in the world in 2019 at 210 GW, followed by the US at 103 GW [35]. *Two*, the US and China are important trading partners. China was the largest source of imports for the US in 2019 with imports worth $451.7 billion. China was also the third largest export market for the US in 2019 with $106.4 billion worth of exports [36]. *Three*, a significant share of the US-China trade, particularly related to the RE industries solar and wind, is impacted by trade tariffs as there have been multiple RE disputes between the two countries since 2011. Given the combination of large RE markets and trade volumes, our focus on the US-China RE trade disputes can provide insights into these major countries and offer implications for others aiming to address multiple climate, energy, and economic development goals.

We conducted the analysis in three steps. In the first step, we reviewed and summarized the major trade disputes in RE industries between the US and China, focusing on the cases where US imposed trade duties on China. For solar energy, we examined US anti-dumping and counter-veiling duties on solar cells and modules from China (2012, 2014, 2018). For wind energy, we examined US anti-dumping and counter-veiling duties on wind towers imported from China (2012) and the import and steel tariffs affecting wind equipment from China (2018). For each case, we reviewed the relevant trade and industry documents to assess the timeline of trade disputes, policies included in trade litigations, and the magnitude of duties imposed.

In the second step, we examined the relationship between when tariffs were imposed and domestic economic goals using employment in the solar or wind sector as the primary indicator. As one of the objectives of green industrial policies is to develop local manufacturing capacity, we used 'manufacturing jobs' as an indicator of the intended employment impacts of trade duties. We also examined jobs in downstream sectors such as installation, operation and maintenance (O&M) that are dependent upon the level of RE installation. Though these jobs are not the motivating factors for imposing trade duties, it is important to assess these downstream jobs to examine the overall employment trends in the RE industries in a country.

In the third step, we examined the relationship between when tariffs were imposed and the climate goals by using solar and wind capacity additions (or deployment) as the indicator. We used annual installations because the power sector is one of the biggest sources of greenhouse gas (GHG) emissions and decarbonization of the power sector and modernization of the energy systems forms a crucial climate mitigation strategy for major economies[2]. We used IRENA's 'Renewable Energy Statistics' report [35] to obtain the RE installation statistics.

Our analysis extended from 2010 to 2019. This timeframe allowed us to analyze whether, and how, the trends in solar and wind manufacturing and capacity addition changed in the US after the imposition of trade duties on imports from one of its biggest trade partners, i.e., China.

A methodological challenge for our analysis was in the availability and quality of data on solar and wind jobs and the temporal changes along different parts of the value chain. We tackled this challenge by reviewing various solar and wind industry reports tracking the job trends in both these sectors in the US. We mainly used annual reports from the Solar Foundation [39] and the US Energy and Employment Reports [40] for US solar and wind job numbers respectively (see supplementary material). In the case of wind, the annual reports only provided total wind job numbers for the years 2011 to 2015 and did not report any distribution withing the sector (i.e., jobs in manufacturing, installation etc.). We estimated the distribution of jobs within the wind sector between 2011 and 2015 using the available total wind jobs and distributing them using average

[2] For example, in the US, electricity generation was the second largest source of GHG emissions in 2019, accounting for 25% of its total emissions [37]. The US aims for to achieve 100% carbon-free power sector by 2035 [38]

sub-sectoral distribution of jobs observed between 2016 and 2019 (i.e., the years for which data is available). However, as an artefact of this calculation, the growth rates for the jobs in the different sub-sectors for the wind industry is the same in our dataset. Overall, these annual reports provide relatively more detailed estimates for downstream sector jobs i.e., the jobs that are dependent on the level of RE installation in comparison to the manufacturing job numbers. This makes the assessment of trade duties on manufacturing jobs difficult because companies are expected to benefit differently from trade duties based on their location in the value chain of the industry. As we discussed in section 2, in the US-China trade disputes, the upstream companies that were engaged in the production of raw materials and equipment used to manufacture solar cells and modules expected to lose out because of trade duties but the manufacturers of components like cells and modules expected to benefit. However, aggregating all manufacturing jobs into a single category, makes it difficult to analyze the differentiated impacts of trade duties. We relied on other sources such as reports by the National Renewable Energy Laboratory to examine the differentiated impacts of trade duties on the solar and wind manufacturing companies in the US. This approach allowed us to assess the broad trends in solar and wind manufacturing jobs in the. A more robust analysis of the employment impacts of trade duties would require disaggregated, time-series data for RE manufacturing jobs, which is not directly available.

We also compared the trends in US solar and wind jobs with the global solar and wind job growth trends. We obtained global RE job trends from annual reports published by IRENA [2]. It should be noted here that job numbers reported by IRENA are not directly comparable to job numbers reported by US sources because of differences in what is reported. For example, for some countries, IRENA includes jobs in off-grid solar which is not included in US estimates. Hence, these employment estimates should be seen as representative of the trends of employment in the solar and wind sector in the US and across the world.

## *4 Results and Discussion*

### *4.1 Trade duties imposed by the US on China on solar photovoltaic technologies*

#### *4.1.1 Overview of the duties imposed*

There are three major instances of the US imposing trade duties on solar technologies from China, described in the following. All three instances are cases of unilateral action where duties were imposed on solar cells and modules imported from China after complaints were filed by the US-based solar cells and module manufacturers domestically.

In 2011, an association of solar manufacturers in the US, the Coalition of American Solar Manufacturing (CASM), complained against the subsidies and dumping of low-cost crystalline silicon photovoltaic solar cells and modules from China in the US. The complaint was submitted to the US Department of Commerce (DOC) and the US International Trade Commission (USITC). During the investigations, USITC found that the US solar industry was being 'materially injured' from the imports because the Chinese cells and modules were highly subsidized[3], and were being sold at less than their fair value in the US. As a response to this, in 2012, the DOC prescribed anti-dumping duties that varied between 18-250% based on the firm from where the solar cells and modules were being imported. Counter-veiling duties were set at around 15% [41].

In 2013, a complaint was again filed by a solar manufacturer, *SolarWorld America*, to the US DOC and USITC. *SolarWorld* argued that the subsidies imposed in 2012 had a "loophole"—they did not include solar modules that were assembled in China but had cells from a third country. This allowed Chinese module manufacturers to bypass the 2012 duties by using cells made in other countries, particularly Taiwan, for module assembly [27]. As a result of this complaint, the US DOC expanded the scope of anti-dumping and counter-veiling duties on imported crystalline silicon photovoltaic cells and modules in the US in 2014. According to the primary litigant *SolarWorld*, the new duties increased the average trade duties on companies to 47%, from the average 31% based on the 2012 duties [42].

More recently in January 2018, the US imposed 'safeguard' duties on imported solar cells and modules after a complaint was made by solar manufacturers *Suniva* and *SolarWorld* to the USITC

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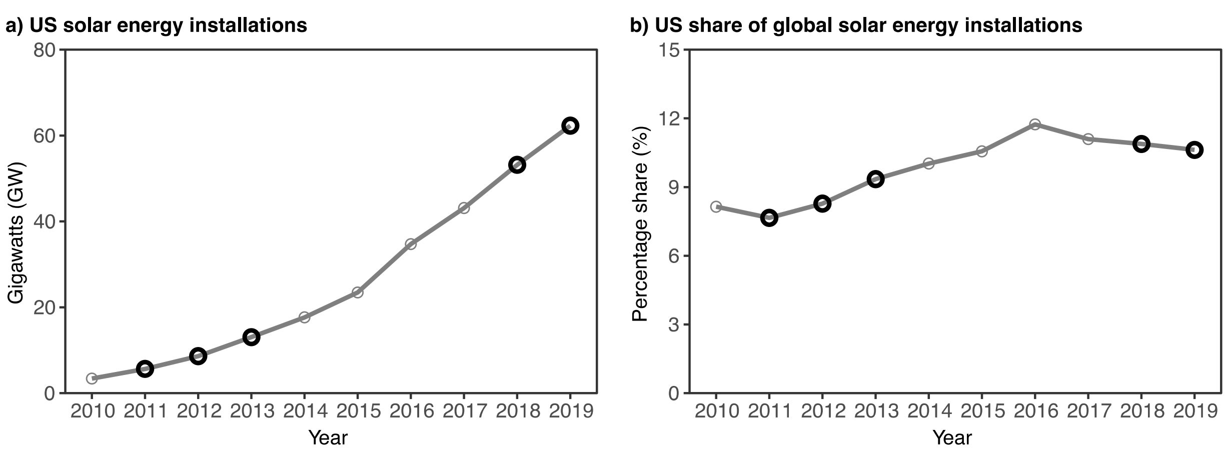
[3] The subsidy programs from the Government of China that were included in the purview of trade duties/countervaible included: Golden Sun Demonstration Program, Preferential Policy Lending, Provision of Polysilicon for less Than Adequate Remuneration (LTAR), Provision of Land for LTAR, Provision of Electricity for LTAR, Preferential Tax Program for High or New Technology Enterprises (HNTEs), Enterprise Income Tax law, Research and Development ("R&D") Program, Import Tariff and Value Added Tax ("VAT") Exemptions for Use of Imported Equipment etc. The full list is available on p. (I-5) of [41].

in 2017. Termed as Section 201 solar tariffs, the US imposed tariffs for four years (2018-2022) starting at 30%, set to decrease by 5% every year. These tariffs were not directed at a particular country, unlike the previous trade duty cases but did include imports from China under their purview [43].

### *4.1.2 Effectiveness of trade tariffs in meeting climate and economic development goals*

We studied the growth in solar installations and solar jobs in the US between 2010 and 2019 in order to understand the impact of US trade duties on achieving multiple domestic goals. We focused on two main time periods, one after the first set of trade tariffs in 2011-2013, and the second after 2018 (see Figure 2).

In terms of deployment, we found that after the trade disputes of 2011-2013, solar capacity additions in the US grew at rates higher relative to worldwide trends, and they remained at or over 10% of global installations from 2012 through 2019. In absolute terms, the total installed solar capacity in the US increased almost 18 times, growing by almost 1700% from 3.4 GW in 2010 to 62.2 GW in 2019 (Figure 2a). In comparison, the global solar installations grew by almost 14 times from 41.5 GW in 2010 to 586.4 GW in 2019. This suggests progress towards climate and energy goals in the US continued at a steady rate despite the imposition of trade duties that potentially affected the cost of solar panels.



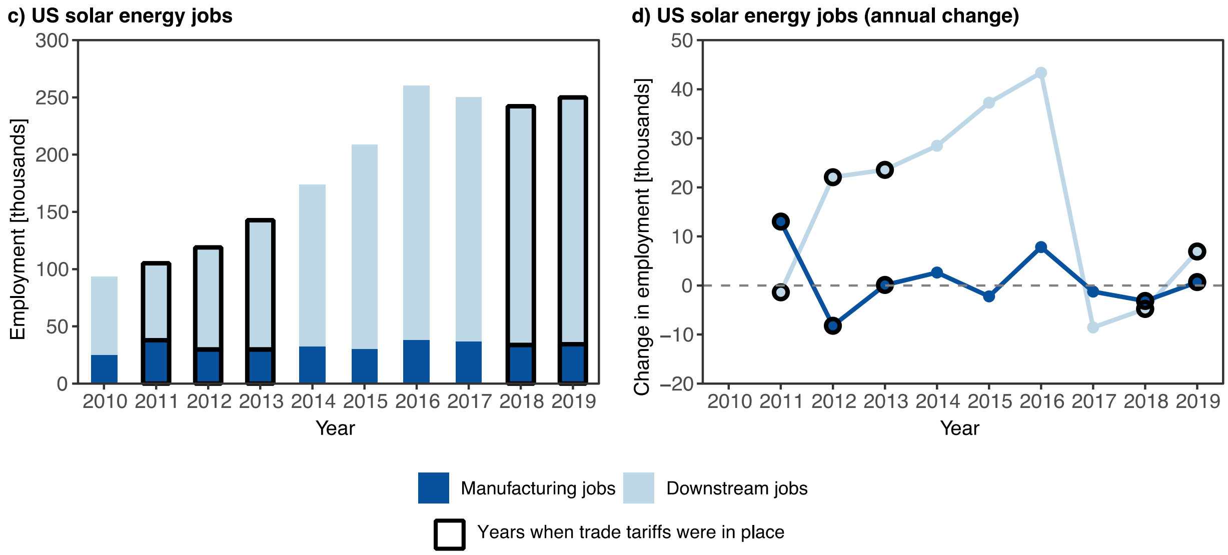



**Figure 2**: Figure 2a presents the cumulative solar capacity installed in the US between 2010 and 2019 (black solid line) and Figure 2b presents the US's share of annual global solar installation between 2010 and 2019 (grey solid line). Figure 2c presents the cumulative solar manufacturing and downstream jobs in the US between 2010 and 2019. Figure 2d presents the annual change in solar manufacturing and downstream jobs in the US between 2010 and 2019. Data source for US and global solar installation is [35]; US solar jobs [39]; global solar jobs [2] The solar installation and jobs data used for these figures are in the supplementary material.

The increase in installations correlated with an increase in downstream jobs, as new installations spurred jobs related to construction, sales and distribution, project development, and O&M (Figure 2c). The downstream solar jobs in the US grew by 214% from around 68,500 to 215,000, between 2010 and 2019. In 2019, a majority of the downstream jobs were in construction (162,000), followed by sales & distribution (30,000), project development and O&M (11,500), and others (12,500) [39]. The decline in downstream jobs after 2016 was likely due to the anticipated expiration of the investment tax credit (ITC), a major policy incentive for installation, that was originally set up to expire at the end of 2016. Although the ITC was extended after review, many of the installations were completed before its expected expiry. Nonetheless, even the reinstatement of the ITC did not help in recovering downstream jobs. Tariffs were announced soon after in 2018 that further led to decline in installation. According to the Solar Energy Industries Association [44], Section 201 tariffs of 2018 increased PV module prices in the US by 43-57% in comparison to the global average, potentially slowing down the rate of solar installation in the US.

The overall growth in installation and downstream jobs observed in Figures 2a and 2b did not correlate with growth in manufacturing or upstream jobs. We found that the imposition of trade duties in 2012-2013 did not help recover the relatively high number of manufacturing jobs in 2011. Despite some annual fluctuations, solar manufacturing jobs in the US remained stagnant at around 35,000 in the past decade (Figure 2c and Figure 2d).

Solar manufacturing jobs did not increase in the US even after the imposition of trade duties on imported cells and modules[4]. The trade duties were negated by the consistently falling prices of PV modules since 2011, where prices of PV modules declined by almost 75% from 1.68$/W in 2011 to 0.38$/W in 2019 [46] thus reducing import prices for the US. The US met most of its growing demand for solar modules from low-cost foreign imports [47]. About three-fourths of the installers reported using imported modules in the 2019 solar census [39]. Between 2011 and 2019, the import of solar modules in the US increased from 2 GW[5] to around 13 GW (US EIA, 2018), whereas annual domestic production of cells and modules did not increase beyond 1 GW until 2019 [48]. However, as a result of trade duties, the US imported a relatively lower share of solar PV from China. As of 2019, although China accounted for more than 60% of the global solar PV shipments [49], the US obtained the majority of its PV imports from Malaysia (38%), followed by Vietnam (25%), South Korea and Thailand (19%). China, along with Hong Kong and Singapore, only accounted for 6% of total imports [50].

Overall, we found that trade duties did not boost local solar manufacturing jobs in the US and these jobs remained stagnant at around 35,000 in the past decade. Instead, trade duties led to an increase in PV module prices in the US thus negating the global price reductions. Overall solar job growth in the US was driven by downstream sector jobs as solar installations in the US continued to grow

[4] Firms manufacturing mounting structures and trackers dominate US solar manufacturing currently, followed by module and monitoring system manufacturers [39]. However, production of some solar-related equipment and raw materials has been declining in the US. Manufacturing of solar inverters was growing till 2016 but since then, producers have been moving out to either consolidate their operations in Europe or shift their manufacturing base to China. Production of polysilicon, an important raw material for solar industry, has also been declining since 2014 [45]

[5] Measured in $GW_{DC}$ – gigawatt direct current

at a steady rate despite the imposition of trade duties, increasing by almost 18 times from 3.4 GW in 2010 to 62.2 GW in 2019.

### *4.2 Wind trade duties imposed by the US on China*

#### *4.2.1 Overview of the duties imposed*

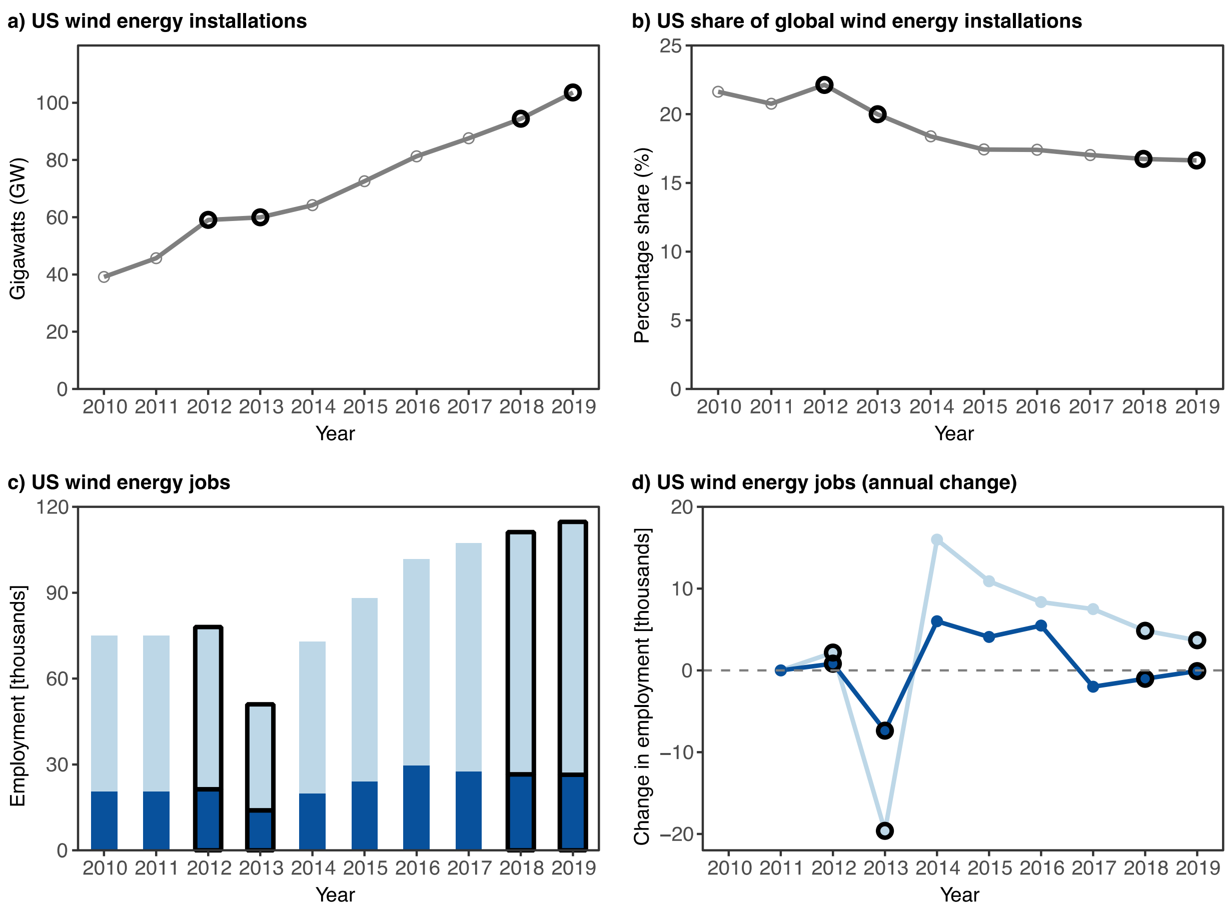
For the wind sector, there are two major instances of the US imposing trade duties on wind equipment from China. First, in 2011, the Wind Tower Trade Coalition (WTTC) filed a complaint at the dumping of utility-scale wind towers from China and Vietnam into the US. The US DOC determined that these imports were causing material injury to wind tower producers in the US, announced preliminary tariffs in May 2012. DOC issued its final ruling in December 2012 and imposed anti-dumping duties between 45-71% and counter-veiling duties between 22-35% on Chinese firms. These duties were approved by USITC in January 2013 [51]. USITC extended the 2013 duties on utility-scale wind towers for another five years in 2018 [52].

Additional tariffs were imposed by the US in 2018 that directly or indirectly impacted wind sector equipment. Based on an investigation carried out by the US Trade Representative (USTR) on the orders of the US President, new tariffs termed as Section 301 tariffs were imposed on Chinese imports concerning various Chinese imports including wind energy components [53]. The lists of wind energy related items on which these tariffs were imposed included gearbox, blades, generators etc. In 2018, tariffs were also imposed on the import of raw and semi-finished steel and aluminum products. Numerous wind companies in the US argued that these tariffs would further harm the domestic wind industry. Cost of production for companies like those involved in tower manufacturing would increase as they relied on imported steel and aluminum for production purposes which, in turn, could increase the cost of wind energy in the US [53].

#### *4.2.2 Effectiveness of trade tariffs in meeting climate and economic development goals*

We studied the growth in wind installations and wind jobs in the US between 2010 and 2019, focusing on two main time periods, one after the first set of trade tariffs in 2012-2013, and the second after 2018 (see Figure 3).

The installed wind capacity more than doubled between 2010 and 2019, from 39 GW to 104 GW (Figure 3a). This suggests that like the solar sector, the wind sector contributed to achieving climate and energy goals even after the imposition of trade duties, and that any changes in prices of components likely did not affect installations. Notably, a decline in new wind installations was observed in 2013 as the production tax credit (PTC), a federal policy that provides tax credit for utility-scale wind generation, was set to expire at the end of 2012. The anticipation of the expiration of wind PTC resulted in a drastic slowdown in wind installations in the US.



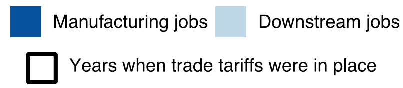



**Figure 3**: Figure 3a presents the cumulative wind capacity installed in the US between 2010 and 2019 (black solid line) and Figure 3b the US's share of annual global wind installation between 2010 and 2019 (grey solid line). Figure 3c presents the cumulative wind manufacturing and downstream jobs in the US between 2010 and 2019. Figure 3d presents the annual change in wind manufacturing and downstream jobs in the US between 2010 and 2019. Data source for US and global wind installation is [35]; US wind jobs [40]; global wind jobs [2]. The wind installation and jobs data used for these figures are in the supplementary material.

The case of wind also highlights that the imposition of trade duties did not spur manufacturing jobs. Growth in wind jobs was also driven by the growth in downstream sector jobs due to the growth in wind installations. Wind jobs grew by 53%, increasing from 75,000 to 115,000, in the US in between 2011 and 2019, with downstream sector jobs growing by 62% from 54,500 in 2011 to 88,000 in 2019. In 2019, most of the downstream wind jobs were in construction (38,000), followed by jobs in professional services (29,000), trade (12,000), utilities (6,000), and others (3,000) [40]. Downstream jobs were correlated with the increase in installations that required these local services.

Although wind installations and associated jobs increased, there was no meaningful impact on manufacturing jobs either after the first instance of tariffs in 2013, or the second instance in 2018. Domestic manufacturing jobs hovered around 25,000 throughout the last decade, and only grew by 29%, increasing from 20,000 in 2011 to 26,000 in 2019. Unlike solar, the annual wind installations in the US have not increased dramatically since 2011, and the US wind manufacturing data suggests that domestic manufacturing capacity for major components such as blades, towers, and nacelle assembly has been enough to meet the annual installation requirements in the US. For example, in 2018, more than 90% of the required nacelle assembly, 65-85% of the wind towers, and 40-70% of blades and hubs required for installation are produced domestically [54]. However, these figures understate the import reliance of the US for wind turbine inputs such as steel or equipment such as mainframes, converters, bolts, controls etc. as these inputs do not get tracked in wind trade data. For example, manufacturer interviews conducted in 2012 suggest that less than 20% of the equipment used for nacelle assembly was produced in the US [54].

Overall, we found that trade duties did not boost local wind manufacturing jobs in the US. While manufacturing jobs remained largely stagnant around 25,000, downstream sector jobs grew in the sector due to the growth in wind installation thus resulting in an overall job growth in the wind sector. These downstream sector jobs were driven by the increase in the installed wind capacity in the US which more than doubled from 39 GW to 104 GW between 2010 and 2019.

### *4.3 Policy implications*

Trade duties did not help in achieving the stated economic development goals of manufacturing job creation as both solar and wind manufacturing jobs remained stagnant even after the imposition of trade duties. Between 2010 and 2019, solar manufacturing jobs in the US hovered at around 35,000 while wind manufacturing jobs increased from 20,000 to 26,000. However, jobs in solar and wind sectors grew overall. This job growth was mainly driven by the growth in downstream jobs owing to the rising solar and wind installations in the US. These downstream jobs were enabled by various policies that incentivized deployment of RE (e.g. the ITC or PTC) and helped advance climate mitigation action. However, coordinated efforts linking deployment and manufacturing remained absent, and relying on trade-duties to enable manufacturing jobs was not effective.

Our findings about the limited contribution of trade duties on the domestic manufacturing employment in the RE industries raises questions on how countries can most effectively develop local RE industries. These questions remain salient for countries across the world because the intersection between climate and energy policy and industry has increasingly become important to gain popular and political support for climate action [11,15,31,32].

Given that RE industries operate in global value chains, and that the development of RE industries in a country is not only determined by the domestic industrial policies but also the green industrial policies in other countries, our analysis points to three approaches that require attention in the context of local RE manufacturing industry development.

First, trade tariffs on one part of the RE technology value chain may be unsynchronized with the systemic nature of energy technologies and the broad goals for simultaneously meeting climate, energy, and economic development goals. Our analysis found that multiple domestic and international factors shape RE industries and therefore employment in RE manufacturing. We found that import tariffs imposed on one part of the value chain, i.e., cells or modules, may negatively affect other parts of the value chain, i.e., raw materials, equipment, or installations.

Second, while policymakers may want to protect domestic manufacturing or spur new manufacturing opportunities with the help of trade tariffs, all components are not equal and focusing on creating competitive advantage in manufacturing may be more effective than imposing trade tariffs. For example, the US imposed tariffs on the imports of wind turbine towers, even though these towers are one of many components in a wind turbine and are among the least complex technologies, which means that many countries have the ability to manufacture them competitively at low cost [8]. Countries should instead focus on developing technologies or parts of the value chain for which they hold competitive advantage over others [8,55]. Without efforts to recognize the characteristics of specific components and build competitive advantage, a country is likely to generate RE jobs only in downstream sectors (such as installations), and not spur manufacturing or exports.

Third, policymakers need to critically evaluate the benefits and tradeoffs associated with trade disputes in RE industries. Our results suggest that trade duties are unlikely to develop local industries on their own and are ineffective in scaling up local RE manufacturing industries in duty-imposing countries. In addition, because trade duties imposed by one country are often a result of green industrial policy in another country, they may also impact industry development in multiple countries. Given that countries worldwide are trying to simultaneously meet climate, energy, economic development goals, many countries have some type of green industrial policy in place against which trade litigations can be raised [13]. The absence of any apparent benefits of trade disputes raises a critical question of whether countries should be raising trade disputes at all.

Given the uncertainty in benefits of trade disputes in RE industries, countries can improve their domestic competitiveness by implementing a wide range of well-designed green industrial policies and effective policy mixes [16,55], rather than relying on trade disputes related to policies such as local content requirements or manufacturing subsidies. Because the policies in question are primarily used in developing and emerging economies to support their nascent RE industries, these countries may also be particularly prone to being the subject of trade disputes. Fighting trade disputes is costly with high financial and human resource requirements [12]. Where well-designed green industrial policies could have helped countries in meeting economic development goals and reducing carbon emissions, some countries may steer away from implementing green industrial policies altogether given the costs associated with trade conflicts. Meanwhile, for developed countries too, in the absence of a coherent approach to green industrial policies, relying on trade duties to spearhead local RE industries is unlikely to develop local industries in the duty-imposing country (e.g., in the US).

Overall, given the current design of international trade laws, instead of spurring local manufacturing industries, trade duties can instead make countries wary of using green industrial policies for local industry development. Researchers studying 'trade wars' in RE industries have suggested reforming international trade rules to reduce the rising conflicts among countries across the world on account of their domestic green industrial policies [12,13,23]

## *5 Conclusion*

In this paper, we reviewed and assessed the relationship between trade duties, local green industry development, and climate action in the context of green industrial policies. RE trade disputes have been rising since 2011 but systematic studies on the effectiveness of these trade duties remain limited. We conceptualized a framework to study the effectiveness of trade duties in meeting economic and climate change mitigation goals and use this framework to examine the case of trade duties imposed by the US on the imports of solar and wind equipment from China. We found that even after imposing trade duties, domestic solar and wind manufacturing did not expand in the US. Solar manufacturing jobs in the US remained stagnant at around 35,000 in the last decade, while wind manufacturing jobs only increased marginally from 20,000 to 26,000. This evidence suggests that while RE trade duties may have maintained some aspects of manufacturing, they had limited success in boosting local RE industry development and manufacturing jobs in the US even as the industry expanded overall.

This paper has the following limitations which can be taken up in future studies. As we mainly focused on examining the trends for solar and wind jobs in the US before and after the imposition of trade duties, this design did not allow us to tease out the impact of only trade duties on solar and wind jobs. Other factors such as policies enacted to encourage solar and wind deployment or other regional skill building programs can also shape job trends in these industries. Future studies on this topic can focus on identifying causal links. However we note that a robust analysis of the employment impact of RE trade duties is constrained by the availability of disaggregated, time-series data for RE manufacturing jobs. We relied on various industry reports for solar and wind sectors to obtain the jobs data for the two sectors. These annual reports provide relatively more detailed estimates for downstream jobs i.e., the jobs that are dependent on the level of RE installation in comparison to the manufacturing jobs, where there is limited data on specific parts of the value chain (e.g. in raw materials vs solar PV modules). However, aggregating all the manufacturing jobs makes it difficult to analyze the differentiated impacts of trade duties. Consequently, using this strategy, we were only able to assess the broad trends in solar and wind manufacturing jobs in the US. Given that creation of manufacturing jobs is an important motivating factor for imposing RE trade duties as well as to seek popular support for climate policies, it is important to collect, and make available data for the different sub-sectors within RE industries.

**Acknowledgements:** Funding for this research was provided by the US National Science Foundation under grant number 1829252. The authors thank the research group at the Center for Global Sustainability for valuable feedback on earlier versions of this article.

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| technology | country | desc | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| solar | China | MW | 1,022 | 3,108 | 6,719 | 17,759 | 28,399 | 43,549 | 77,809 | 130,822 | 175,237 | 205,493 |
| solar | US | MW | 3,382 | 5,644 | 8,613 | 13,045 | 17,651 | 23,442 | 34,716 | 43,115 | 53,184 | 62,298 |
| solar | World w/o China | | 40,520 | 70,626 | 97,359 | 121,823 | 147,619 | 178,444 | 218,012 | 257,735 | 313,515 | 380,941 |
| solar | World | MW | 41,542 | 73,734 | 104,078 | 139,582 | 176,018 | 221,993 | 295,821 | 388,557 | 488,752 | 586,434 |
| | | | | | | | | | | | | |
| wind | China | MW | 29,633 | 46,335 | 61,597 | 76,731 | 96,819 | 131,048 | 148,517 | 164,374 | 184,665 | 210,478 |
| wind | US | MW | 39,135 | 45,676 | 59,075 | 59,973 | 64,232 | 72,573 | 81,286 | 87,597 | 94,417 | 103,584 |
| wind | World w/o China | | 151,217 | 173,685 | 205,312 | 223,189 | 252,481 | 285,228 | 318,310 | 350,028 | 379,155 | 412,226 |
| wind | World | MW | 180,850 | 220,020 | 266,909 | 299,920 | 349,300 | 416,276 | 466,827 | 514,402 | 563,820 | 622,704 |

**Supplementary table 1**: Trends in solar and wind installation between 2010 and 2019. The installation numbers are in MW. The installation statistics have been obtained from IRENA's 'Renewable Energy Statistics' report [1].

| **tech** | **country** | **desc** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| solar | USA | Installation | 43,934 | 48,656 | 57,177 | 69,658 | 97,031 | 119,931 | 137,113 | 129,424 | 155,157 | 162,126 |
| solar | USA | Sales and Distribution | 11,744 | 13,000 | 16,005 | 19,771 | 20,185 | 24,377 | 32,147 | 30,912 | 29,243 | 29,798 |
| solar | USA | Project Development, O&M | - | - | 7,988 | 12,169 | 15,112 | 22,452 | 34,400 | 35,750 | 11,164 | 11,583 |
| solar | USA | Other | 12,908 | 5,548 | 8,105 | 11,248 | 8,989 | 11,816 | 18,274 | 17,300 | 13,053 | 12,053 |
| solar | USA | Downstream | 68,586 | 67,204 | 89,275 | 112,846 | 141,317 | 178,576 | 221,934 | 213,386 | 208,617 | 215,560 |
| solar | USA | Manufacturing | 24,916 | 37,941 | 29,742 | 29,851 | 32,490 | 30,282 | 38,121 | 36,885 | 33,726 | 34,423 |
| solar | USA | Total | 93,502 | 105,145 | 119,017 | 142,697 | 173,807 | 208,858 | 260,055 | 250,271 | 242,343 | 249,983 |
| solar | World | Total | | | 1,360,000 | 2,273,000 | 2,495,000 | 2,772,000 | 3,095,000 | 3,370,000 | 3,605,000 | 3,755,000 |
| | | | | | | | | | | | | |
| wind | USA | Construction | 26,661 | 26,661 | 27,728 | 18,130 | 25,950 | 31,283 | 37,847 | 36,424 | 36,706 | 37,910 |
| wind | USA | Trade | 9,411 | 9,411 | 9,788 | 6,400 | 9,160 | 11,043 | 14,243 | 11,926 | 11,783 | 12,305 |
| wind | USA | Professional Services | 12,416 | 12,416 | 12,912 | 8,443 | 12,085 | 14,568 | 12,310 | 22,563 | 27,058 | 28,873 |
| wind | USA | Utilities | 3,638 | 3,638 | 3,784 | 2,474 | 3,541 | 4,269 | 4,171 | 6,017 | 6,231 | 6,360 |
| wind | USA | Others | 2,400 | 2,400 | 2,496 | 1,632 | 2,336 | 2,816 | 3,764 | 2,901 | 2,898 | 2,918 |
| wind | USA | Downstream | 54,526 | 54,526 | 56,707 | 37,078 | 53,072 | 63,977 | 72,336 | 79,831 | 84,676 | 88,366 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| wind | USA | Manufacturing | 20,474 | 20,474 | 21,293 | 13,922 | 19,928 | 24,023 | 29,504 | 27,506 | 26,490 | 26,408 |
| wind | USA | Total | 75,000 | 75,000 | 78,000 | 51,000 | 73,000 | 88,000 | 101,840 | 107,337 | 111,166 | 114,774 |
| wind | World | Total | | | 753,000 | 834,000 | 1,027,000 | 1,081,000 | 1,155,000 | 1,148,000 | 1,160,000 | 1,165,000 |

**Supplementary table 2:** Trends in solar and wind jobs between 2010 and 2019. Downstream jobs for solar in the US are calculated by adding installation, sales and distribution, projection development, O&M and other jobs. Downstream jobs for wind in the US are calculated by adding construction, trade, professional services, utilities, and other jobs. Data sources are annual industry reports between years 2010 and 2019. Technology- and country-wise data sources are as follows:
US solar jobs - The Solar Foundation [2]
US wind jobs - National Association of State Energy Officials & Energy Futures Initiative (2020). For some wind jobs statistics between years 2010 and 2015, we relied on annual reports by American Wind Energy Association (AWEA) [3]
World solar and wind jobs – IRENA Annual Jobs review [4]

**Supplementary references:**


1. IRENA. Renewable Energy Statistics 2020 [Internet]. 2020d p. 408. Available from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Renewable_Energy_Statistics_2020.pdf

2. The Solar Foundation. National Solar Jobs Census [Internet]. The Solar Foundation. 2021 [cited 2021 Apr 29]. Available from: https://www.thesolarfoundation.org/national/

3. National Association of State Energy Officials, Energy Futures Initiative. 2020 U.S. Energy and Employment Report (USEER) [Internet]. 2020 U.S. Energy and Employment Report (USEER). 2020 [cited 2021 Apr 29]. Available from: https://www.usenergyjobs.org

4. IRENA. Renewable Energy and Jobs – Annual Review 2020. 2020 p. 44.