BENCHMARKS OF GLOBAL CLEAN ENERGY MANUFACTURING

CEMAC Clean Energy Manufacturing Analysis Center

Operated by the Joint Institute for Strategic Energy Analysis

Foreword

Thomas Catania, Chair of the CEMAC External Advisory Committee[1]

Clean energy supply chains reflect the outcomes of the past decades of investment in industrial and economic development. Competition among locations for manufacturing facilities is a long established practice in which there are winners and losers over the short to medium term. In the long run, a future world where energy is clean, cheap and abundant for everyone will benefit all economies, but that future world will only emerge from competition. As events in the oil market over the past couple of years demonstrate, short-term convulsions have real and substantial consequences for individual economies throughout the world.

Analyzing the clean energy manufacturing portion of global and national economies is no easy task. The CEMAC Advisory Committee encouraged the CEMAC staff to drink deeply from all available resources that go beyond the underlying technologies, where our national labs have long demonstrated tremendous competence. More opaque variables such as international trade policies and practices, tax policy (both as stated and applied), subsidies, and the impact of relative positions of currencies can sometimes be the deciding variables in the business analysis equation.

This manufacturing benchmark report makes a timely, important, and unique contribution to our knowledge bank by providing detailed and nuanced information about manufacturing value added, capacity, and trade for important clean energy technologies. In combination with the detailed technical reports and insights from CEMAC, the benchmark report can help us all make better informed choices. We anticipate these benchmarks to be heavily tagged and annotated by real world practitioners. Yet, this work can only be as good and useful as the quality of the information to which CEMAC has access. The CEMAC Advisory Committee appeals to members of the private and public sector actively engaged in clean energy manufacturing, or its promotion, to engage with CEMAC and share their real world examples of what is required to be successful and what is actually happening on the ground.

On behalf of the Advisory Committee, I would like thank the staff of CEMAC and its sponsor, the U.S. Department of Energy, for their willingness to solicit and accept advice and feedback throughout the process of developing this report. The Committee has been provided ample opportunities to share its expertise from spanning the public and private sectors, the academic community and non-governmental organizations with broad and deep involvement in the clean energy sector. We appreciate the opportunity to support this important report.

1. The membership of the CEMAC Advisory Committee can be found at http://www.manufacturingcleanenergy.org/about.html.

Preface

Jill Engel-Cox, Ph.D., Director, Clean Energy Manufacturing Analysis Center

A benchmark is a point of reference against which things may be compared or assessed.

With this report, the Clean Energy Manufacturing Analysis Center (CEMAC) provides a benchmark of clean energy technology manufacturing around the world, a reference point against which we can compare over time as the clean energy revolution unfolds. We look at where key technologies are made, where they are used, and offer insights as to why markets are as they are. We examine four technologies across their manufacturing supply chains, including processing raw materials, making the required subcomponents, and assembling the final product. Then, to facilitate comparisons between these four technologies and 12 key economies, we describe each technology in terms of four common benchmarks:

- *Manufacturing value added*
- *Global trade*
- *Market size*
- *Manufacturing capacity and production.*

We hope that the data and insights provided by these benchmarks can help set research agendas, inform trade policies, and determine manufacturing opportunity by location and technology. We appreciate our sponsors at the U.S. Department of Energy for making this research possible.

This report is timely since clean energy technology deployment is growing exponentially, at the same time that manufacturing is in the midst of revolutionary change toward increasingly global supply chains, automation, and decentralized manufacturing. These changes create tremendous opportunities for innovation and economic development in the United States and the world, including dynamic industrial processes, sustainable materials, and advanced manufacturing technologies, as well as the high-tech labor force that will create and operate them.

Our goal at CEMAC is to inform policymakers and industry leaders as they advance the clean energy economy. We look forward to hearing from you about how you use this report and to working with you on future analyses.

Acknowledgments

The principal investigators of this report—Debra Sandor, Donald Chung, David Keyser, Margaret Mann, and Jill Engel-Cox—would like to acknowledge the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy for their support for the development of this report. We also acknowledge the members of the CEMAC Advisory Committee for their advice throughout the development process. Key expert input was provided by Dr. Ed Balistreri, Colorado School of Mines, and Dr. Rebecca Hill, Colorado State University. Many analysts within CEMAC made major contributions, including Samantha Reese, Kelsey Horowitz, Chris Scarlata, Chris Moné, Eric Lantz, Tian Tian, Jon Weers, and Billy Roberts. We also appreciate the editorial support of Scott Gossett and the design services of Stacy Buchanan. Operational support by the Joint Institute for Strategic Energy Analysis and NREL, and strategic counsel of Doug Arent have been instrumental to CEMAC and this Benchmark Report.

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List of Acronyms

ANL	Argonne National Laboratory
BEA	United States Bureau of Economic Analysis
BEV	battery electric vehicle
BLS	United States Bureau of Labor Statistics
BNEF	Bloomberg New Energy Finance
CAGR	compound annual growth rate
CEMAC	Clean Energy Manufacturing Analysis Center
C-Si	crystalline silicon
DMC	dimethyl carbonate
DOE	U.S. Department of Energy
EC	ethylene carbonate
EMC	ethyl methyl carbonate
EV	electric vehicle
FD	final demand
GaN	gallium nitride
GDP	gross domestic product
GWh	gigawatt hour
HEV	hybrid electric vehicle
HTS	harmonized tariff schedule
I-O	input-output
ISIC	International Standard Industrial Classification
ITC	International Trade Centre
JISEA	Joint Institute for Strategic Energy Analysis
kg	kilogram
LDV	light duty vehicle
LED	light-emitting diode
M	million
MW	megawatts
NAICS	North American Industry Classification System
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Cooperation and Development
PHEV	plug-in hybrid electric vehicle
PV	photovoltaic
SAM	social accounting matrix
SiC	silicon carbide
STAN	structural analysis
USD	U.S. dollar
USITC	United States International Trade Commission
VA	value added
WTO	World Trade Organization

EXECUTIVE SUMMARY

Executive Summary

Clean energy technologies are expanding rapidly and growing in significance with respect to contributing to the world's energy systems. The manufacture of these technologies—including extracting and processing raw materials, producing required subcomponents, and assembling end product—has become a global enterprise.

The Clean Energy Manufacturing Analysis Center (CEMAC), sponsored by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) provides objective analysis and up-to-date data on global supply chains and manufacturing of clean energy technologies. CEMAC analysts prepared *Benchmarks of Global Clean Energy Manufacturing* to shed light on several fundamental questions about the global clean technology manufacturing enterprise:

- How does clean energy technology manufacturing impact national economies?
- What are the economic opportunities across the manufacturing supply chain?
- What are the global dynamics of clean energy technology manufacturing?

To address these questions, we establish a set of benchmarks to track global changes in clean energy manufacturing and provide a baseline, based on 2014 data. We selected four leading technologies from the multitude contributing to the growing clean energy space: wind turbine components (blade, tower, nacelle), crystalline silicon (c-Si) solar photovoltaic (PV) modules, light duty vehicle (LDV) lithium ion battery cells, and light emitting diode (LED) packages for lighting and other consumer products. These each represent the final product that is traded in their respective supply chains, among other criteria defined in the methodology (CEMAC 2017).

The impacts of the manufacturing supply chain for these four technologies are assessed in terms of common benchmarks for 12 economies, selected because they comprise the primary manufacturing hubs for the four technologies: Brazil, Canada, China, Germany, India, Japan, Malaysia, Mexico, South Korea, Republic of China (Taiwan), United Kingdom, and United States.

Approach

This work establishes a common framework and new methodologies for assessing and comparing clean energy technology manufacturing supply chains, aligned with CEMAC's standardized manufacturing cost analysis methodology (CEMAC 2017).

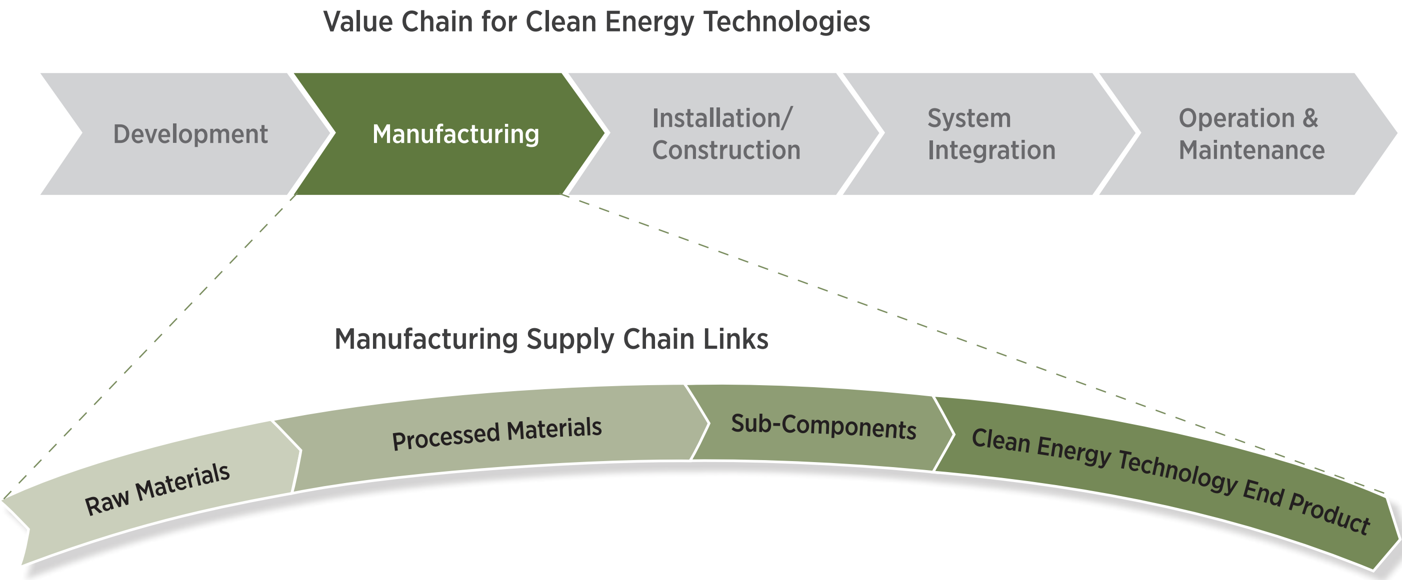


Figure ES-1. Value chain with manufacturing supply chain links for clean energy technologies

Framework

Manufacturing is just one piece of the larger clean energy economy, yet it is the linchpin between technology development and its deployment into the marketplace (see Figure ES-1). Upstream, innovation in the development stage has economic value in the intellectual property, research, and corporate management. Downstream, the installation, systems integration, and operations, which are inherently highly localized, bring economic value through employment, services, property taxes, and reduction of pollution and environmental impact. While tremendous value can be found in the development and deployment of technologies, this report focuses on the value added and opportunities found in the manufacturing supply chain.

We examine each technology in terms of four common manufacturing supply chain links: raw materials, processed materials, sub-components, and end product. This framework provides a consistent basis for aggregation and comparison of a diverse set of clean energy technologies and manufacturing processes. To make this benchmarking exercise manageable, the specific materials, intermediates, and subcomponents included within each link were limited based on an assessment of: raw material constraints, uniqueness or role as an enabling process or product, global trade in that item, impact on overall cost, and contribution to quality.

Alignment of the technologies with the manufacturing supply chain framework is illustrated in Figure ES-2.

Methodologies

We established four common points of reference—benchmarks—to provide a standardized basis for (1) comparing key economic aspects of clean energy technology manufacturing on a national and global basis, and (2) tracking changes as markets and manufacturing processes evolve. New methodologies were developed to establish each benchmark while accommodating the variations in clean energy technology manufacturing supply chains and availability of data. The methodologies are outlined here and detailed in the methodology report (CEMAC 2017).

Benchmark 1: Clean Energy Manufacturing Value Added

This benchmark provides insight into the contribution and importance of clean energy manufacturing to national economies.

Value added is a key component of national gross domestic product (GDP). It has two components defined as:

- *Direct value added* is the amount that clean energy manufacturers themselves contribute to national GDP. This includes payments to manufacturing workers,

Raw Materials	Processed Materials	Sub-Components	Clean Energy Technology End Product
Silica, Silver	**Polysilicon,** Silver Paste, Glass	**C-Si PV Wafer, C-Si PV Cell,** Frame, Encapsulant	**C-Si Solar PV Module**
Iron, Neodymium, or Dysprosium Ores	**Steel,** Fiberglass, Carbon Fiber, Neodymium and Dysprosium Alloys	Permanent Magnets, **Generators,** Gear Assemblies, Steel Components	**Wind Turbine Components: Blades, Tower, Nacelle**
Lithium, Cobalt, Nickel, Graphite Ores	**Cathode Materials, Anode Materials, Electrolytes**	**Separators,** Housings, Metal Foils, Tabs	**Light Duty Vehicle (LDV) Li-ion Battery Cell**
Gallium, Indium, Yttrium Ores	**Sapphire Substrates,** Trimethyl Gallium (TMG), Trimethylindium (TMI), YAG Phosphors	**LED Chips**	**LED Package**

Figure ES-2. Clean energy manufacturing supply chain links

Items in bold are included in the benchmark analysis. This analysis covers the processed materials, subcomponents, and end product elements; we excluded raw materials due to the difficulty of reliably allocating the share of consumption of widely used raw materials to specific clean energy technologies.

property-type income such as profits earned by owners and investors, and taxes paid on production less government subsidies.

- *Indirect value added* is often referred to as the economic ripple effect. When clean energy manufacturers make products they purchase inputs such as accounting services or raw materials. A generator manufacturer, for example, may purchase copper wiring from a domestic wire manufacturer. This wire manufacturer and its contribution to GDP would be included in the indirect effect.

We estimate manufacturing value added using a combination of CEMAC cost analysis data, market data, and social accounting data from the Organization for Economic Cooperation and Development (OECD) Structural Analysis (STAN) Input-Output (I-O) database.[2]

Benchmark 2: Clean Energy Trade

This benchmark provides insight into global clean energy trade activity and interconnectedness across the manufacturing supply chain.

Trade connects the global community and can be a significant source of economic growth. Balance of trade (exports less imports) is another key component of national GDP. Trade flow data for the benchmark report are compiled from the United States International Trade Commission (USITC) and the International Trade Centre.[3] Trade data are in U.S. dollars (USD) rather than local currencies. Fluctuation in trade that is measured in a standard currency such as USD can be caused by changes in the volume of trade or the value of the local currency relative to the USD. A relatively strong domestic currency makes exports more expensive in the international market while a weaker currency makes them less expensive. While official trade data for the final products is often available, the upstream data are often intertwined with much larger industry sectors and difficult to extract for the specific technology of interest. Where not available, the balance of trade for upstream components was estimated using market data from secondary sources.

Benchmark 3: Clean Energy Market Size

This benchmark provides insight into the relative concentration of demand for clean energy technologies across the globe.

Market size (or market demand) data were collected from existing secondary sources to estimate the market size for each technology across the manufacturing supply chain and in each economy. When available, actual production data for each subsequent downstream intermediate formed the basis of demand estimates for key supply chain intermediates. When data were not available, typically for smaller industries (LED packages and LDV Li-ion battery cells), the demand for intermediates was approximated by assuming that the production volume of the end product is equivalent to the demand for each upstream intermediate product. The monetary value of demand was estimated by applying estimates of average global unit prices to allow comparison across technologies and economies.

Benchmark 4: Clean Energy Manufacturing Capacity and Production

This benchmark provides insight into the clean energy manufacturing capacity and production around the world and highlights opportunities for expansion to meet demand.

Manufacturing capacity and production were estimated to highlight the economies that make the largest contributions in each category and to understand where excess capacity is located around the world for each technology. Like market size data, data were collected from existing secondary sources, and monetary values were estimated by applying estimates of average global unit prices to (1) allow comparison across technologies and economies and (2) provide input for the value added benchmark based on production value of each technology and intermediate.

2. Further information about the OECD STAN I-O database, including the data used in the benchmark study, can be found at http://www.oecd.org/sti/ind/stanstructuralanalysisdatabase.htm.

3. Further information about the USITC can be found at https://www.usitc.gov/ and further information about the International Trade Centre is at http://trademap.org.

Benchmark Data

The baseline year for this report is 2014, the most recent year for which reliable, comprehensive data are available. We draw from public, proprietary sources, primary, and secondary sources. For the technologies considered here, clean energy technology end product information is relatively complete; however, data needed to estimate the benchmarks at the desired level of supply chain disaggregation are not available for all the technologies. Consequently, data reported here vary in level of confidence. The data sources, assumptions and data confidence are detailed in the technology discussion of the main report and in the methodology report (CEMAC 2017).

Results and Findings

The benchmark analysis points to nine key conclusions about the global impacts of manufacturing wind turbine components, c-Si PV modules, LED packages, and LDV Li-ion battery cells in 2014. The key findings are summarized in Table ES-1.

Table ES-1. Summary of Benchmark Report Findings for 2014 Market, Manufacturing, and Trade Data

Benchmark	Findings
Benchmark 1: Clean Energy Manufacturing Value Added	**1a.** Manufacturing value added for c-Si PV modules, wind turbine components, LED packages, and LDV Li-ion battery cells is highest for China, Japan, Germany and the United States and lowest for the United Kingdom, Mexico, and Canada. **1b.** While clean energy manufacturing is a small contributor to national GDP in all economies considered, manufacturing of the four clean energy technologies contributes about 10 times more to manufacturing sectors of Taiwan and Malaysia than to the manufacturing sectors of the United Kingdom, Mexico, and the United States. **1c.** For the four clean energy technologies, a greater share of direct manufacturing production revenue is retained as value added in the United States, United Kingdom, and Canada than in Malaysia, China, and India. In addition, the indirect value added, or economic ripple effect, of clean energy manufacturing is greatest in China, Mexico, India, and Brazil. **1d.** For the economies included in the analysis, direct manufacturing value added retained is higher for polysilicon, LDV Li-ion battery cells, and wind towers and blades and lower for steel (for wind towers), electrolytes, anodes, and separators (for Li-ion battery cells).
Benchmark 2: Clean Energy Trade	**2a.** A dynamic trade network connects the 12 economies that manufacture the four clean energy technologies. In total, China, Taiwan, Malaysia, South Korea, and Germany are net exporters of the clean energy technology end products considered. The remaining seven economies are net importers, although this varies by technology and supply chain link. **2b.** The end product trade is part of a more complex story. Economies that are net importers of end products may be major exporters of upstream processed materials and subcomponents of those same technologies. For example, the United States is a net exporter of polysilicon but a net importer of c-Si PV modules.
Benchmark 3: Clean Energy Market Size	The manufacturing of clean energy technologies studied contribute to markets of widely varying sizes, ranging from the $45 billion wind industry to the $2 billion automotive lithium-ion cell battery industry. Economy specific demand patterns vary across the technologies.
Benchmark 4: Clean Energy Manufacturing Capacity and Production	**4a.** Production of wind turbine components and c-Si PV modules is more concentrated than production of LED chips and LDV Li-ion battery cells. Wind components are typically made in the same economies that have high demand, but manufacturing and demand for c-Si PV modules, LED chips, and LDV Li-ion battery cells are less coincident. **4b.** Across the four clean energy technologies evaluated, in 2014 there was generally an excess of manufacturing capacity, relative to global demand.

Benchmark 1.
Clean Energy Manufacturing Value Added:

1a. Manufacturing value added for c-Si PV modules, wind turbine components, LED packages, and LDV Li-ion battery cells is highest for China, Japan, Germany and the United States and lowest for the United Kingdom, Mexico, and Canada.

The total clean energy manufacturing value added is shown in Figure ES-3, for the four clean energy technologies. China accrued the largest value added overall (USD 38.8 billion) from clean energy manufacturing in 2014; Japan, Germany, and the United States were second, third and fourth, with USD 7.1 billion, USD 6.3 billion, and USD 6.2 billion, respectively. The manufacturing value added indicates the contribution of the manufacturing toward the national GDP, thus larger numbers are one indicator of the strength of clean energy manufacturing in the economy.

1b. While clean energy manufacturing is a small contributor to national GDP in all economies considered, manufacturing of the four clean energy technologies contributes about 10 times more to manufacturing sectors of Taiwan, and Malaysia, than to the manufacturing sectors of the United Kingdom, Mexico, and the United States.

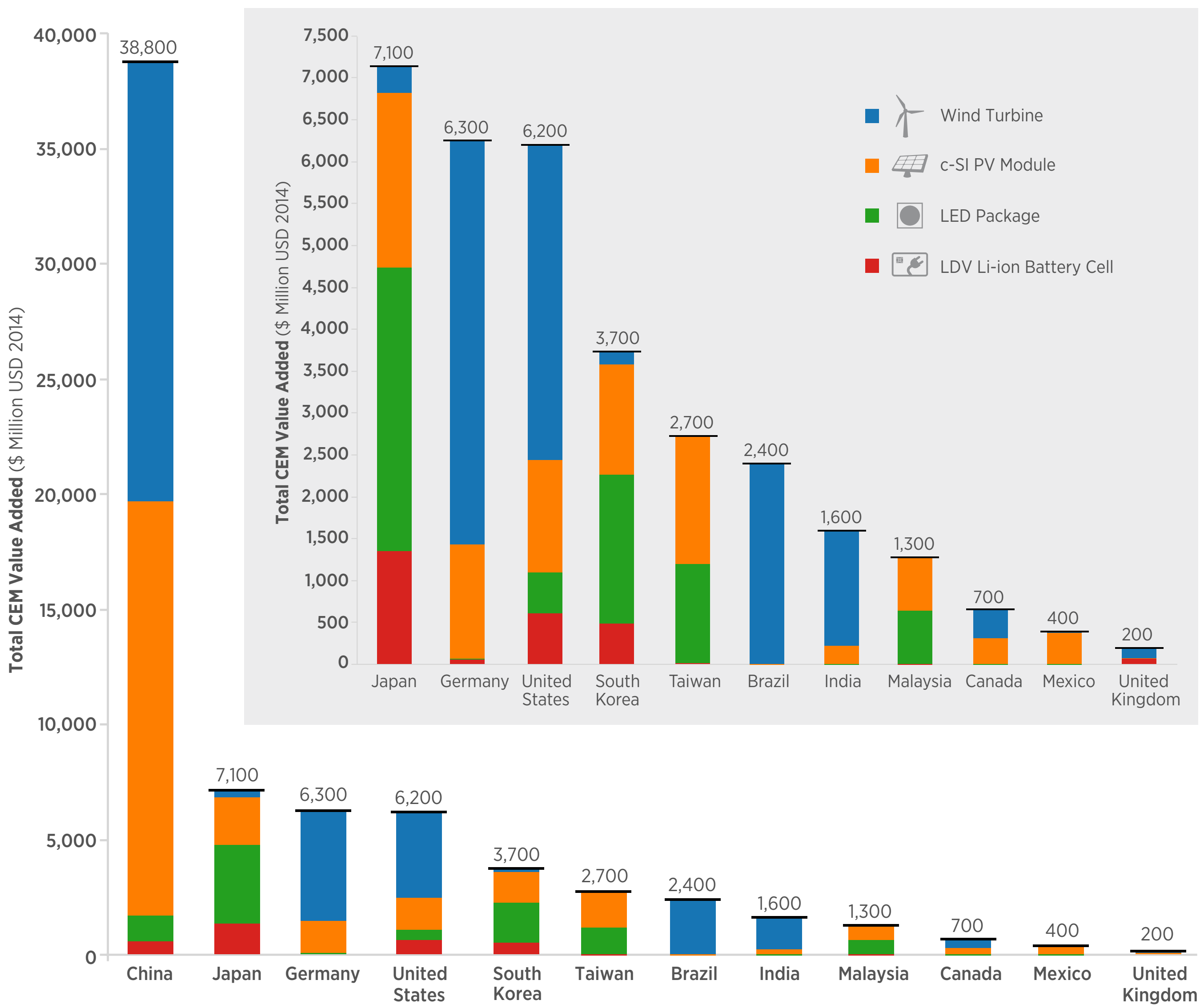


Figure ES-3. Manufacturing value added for four clean energy technologies, 2014

Total clean energy manufacturing value added is aggregated across the supply chain for the four clean energy technologies by economy in Figure ES-3. See methodology report for data quality discussion.

To put value added into more context given the wide variability of national populations, resources, and economies, Figure ES-4 summarizes the contribution of manufacturing of these four clean energy manufacturing technologies to the total manufacturing sector in terms of supporting GDP. The economic contribution from manufacturing of the four clean energy technologies considered ranged from a high of 0.28% for Taiwan to a low of 0.01% for the United Kingdom. This economic activity is not a large portion of the individual economies because each produces a diverse mix of other goods and services. Comparing across the 12 economies, however, does show the importance of clean energy manufacturing in each. For example, the United States has the largest GDP and the second largest contribution by manufacturing, but the four clean energy technologies are a relatively small part. Taiwan and Malaysia are small economies but clean energy technology manufacturing plays a relatively large part of their GDP.

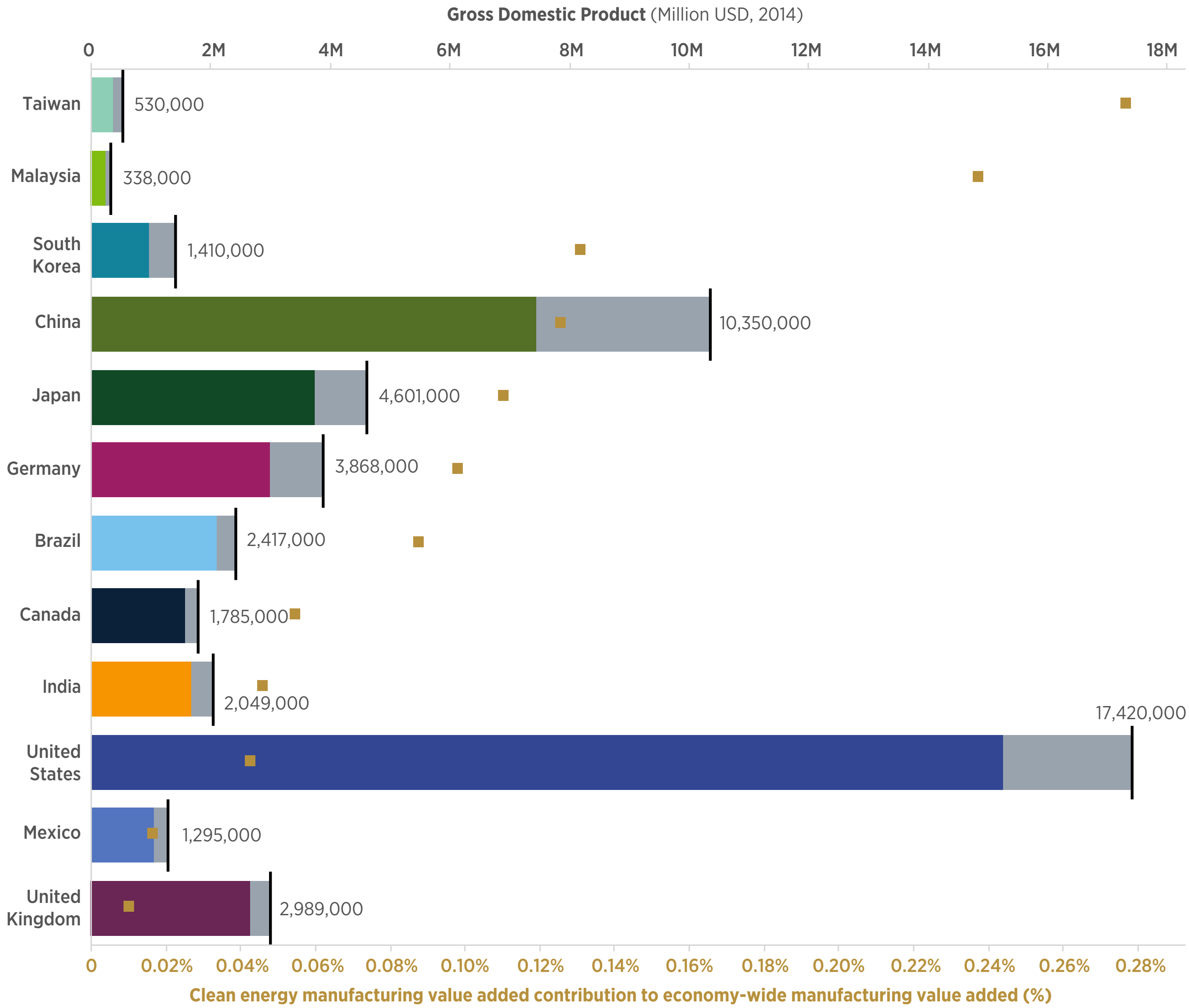


Figure ES-4. National GDP and direct clean energy manufacturing value added (for four clean energy technology supply chains) as a share of total manufacturing value added, 2014

Total bar length shows national GDP in Million USD (annotated), gray shading indicates manufacturing value added contribution to GDP, and the squares indicate clean energy manufacturing direct value added as a fraction of manufacturing value added for each economy (bottom axis). See methodology report for data quality discussion.

1.c For the four clean energy technologies, a greater share of direct manufacturing production revenue is retained as value added in the United States, United Kingdom, and Canada than in Malaysia, China, and India. In addition, the indirect value added, or economic ripple effect, of clean energy manufacturing is greatest in China, Mexico, India, and Brazil.

Normalizing the direct clean energy manufacturing value added for the four technologies by production revenue (value added retained) provides insight on the extent that the manufacturing supply chain associated with these clean technologies is domestically sourced and shows how much clean energy manufacturing workers, investors, and governments within each economy gain from each unit of production (Figure ES-5). The highest value added retained is shown in the United States (57%), United Kingdom (46%), Canada (41%), and Germany (40%). Malaysia (16%), China (18%), and India (20%) show the lowest.

Larger economies such as the United States tend to retain higher percentages of clean energy manufacturing value added as a portion of revenue than smaller economies

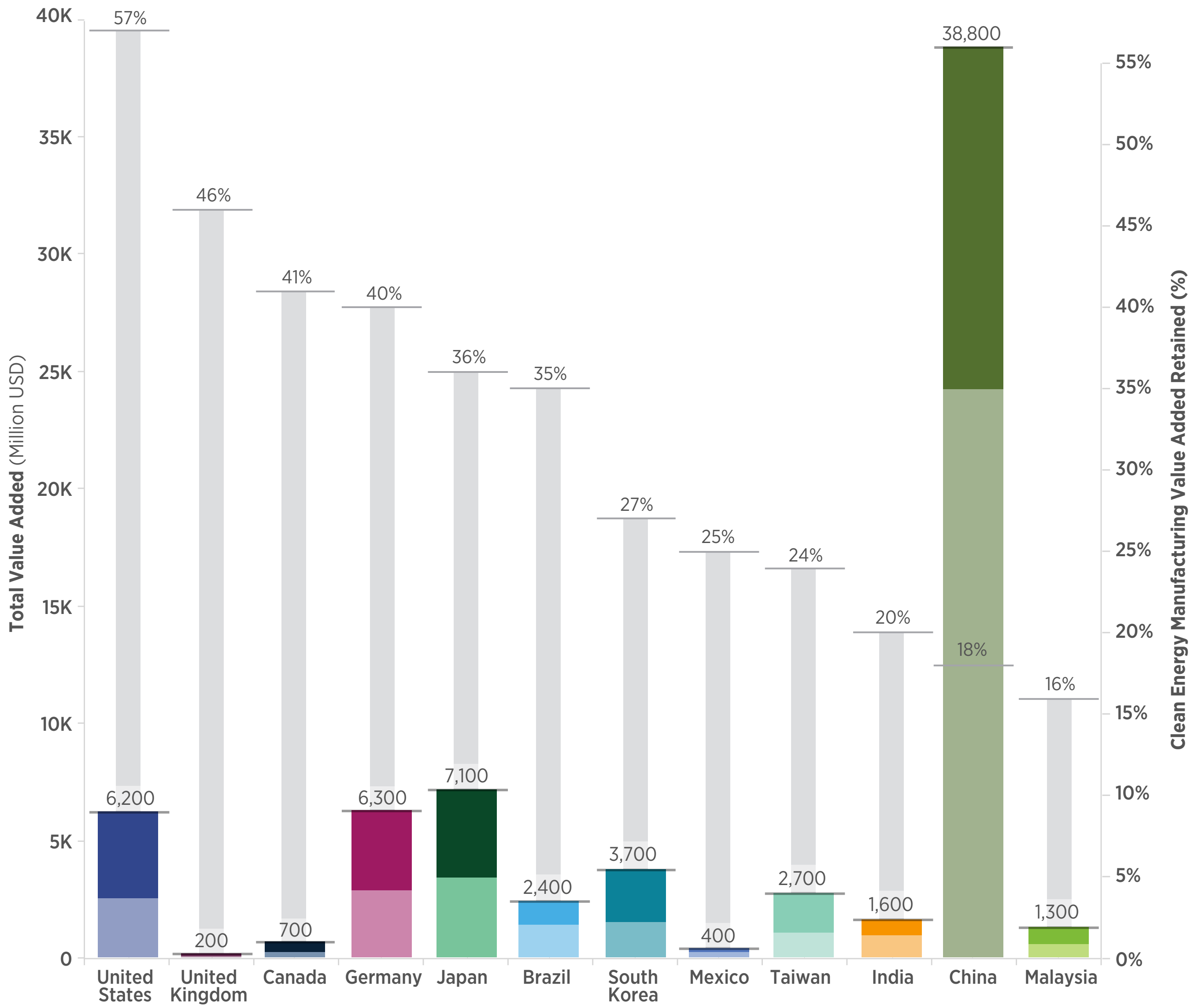


Figure ES-5. Direct manufacturing value added retention (share of production revenue) for four clean energy technology supply chains, 2014

The color bars indicate the total clean energy manufacturing value added for each national economy (darker shading shows the direct value added and lighter shading shows the indirect value added); value added retained within each economy is indicated by the gray bars. See methodology report for data quality discussion.

such as Malaysia and Taiwan. Higher retained value added is an important indicator of how connected industries are to the economy as a whole. The differences in the amount of value added retained are influenced by a number of domestic economic factors, such as prevailing wages, taxes, and subsidies. These also vary from industry to industry. High tech manufacturing, for example, might need more skilled and expensive workers relative to other types of manufacturing. Different products can also have lower labor intensity relative to capital intensity. If returns on capital are high, then this will push up the value added share of production revenue even if there are fewer jobs.

Figure ES-5 also highlights the relationship between direct and indirect value added from clean energy manufacturing. Of the 12 economies considered, the ripple effect is greatest in China, Mexico, India, and Brazil, where more indirect value added than direct value added is generated from manufacturing the four clean energy technologies. A well-developed domestic supply chain will result in greater levels of indirect value added than a supply chain that relies on imported goods and services.

1d. For the economies included in the analysis, direct manufacturing value added retained is higher for polysilicon, LDV Li-ion battery cells, and wind towers and

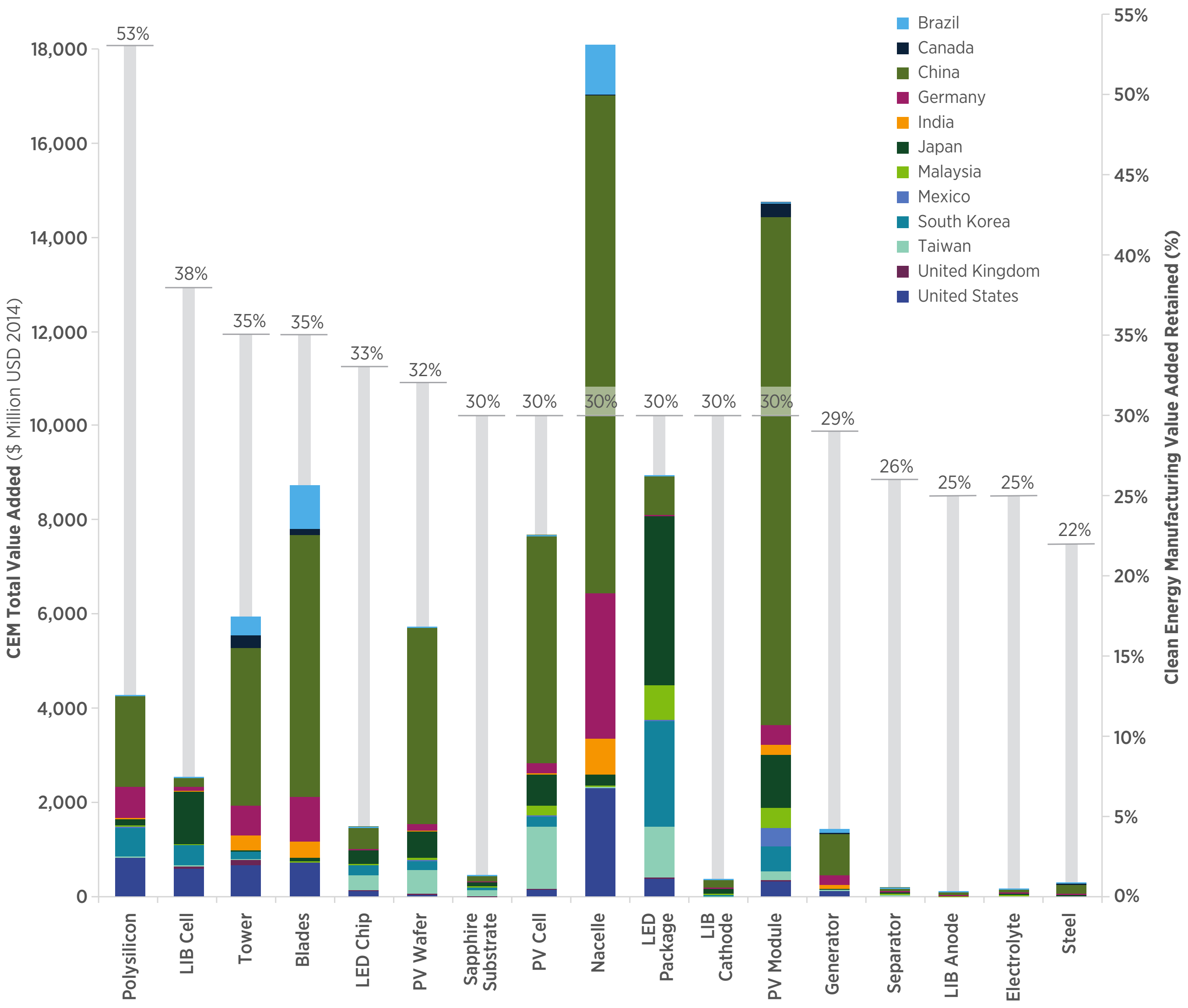


Figure ES-6. Direct manufacturing value added retained for four clean energy technology supply chain intermediates across 12 economies, 2014

The color bars show, by technology intermediate, the total clean energy manufacturing value added in each of the 12 economies, and the gray bars show direct manufacturing value added retained. See methodology report for data quality discussion.

blades and lower for steel (for wind towers), electrolytes, anodes, and separators (for LDV Li-ion battery cells).

Direct manufacturing value added retained varies across the four clean energy technology supply chains assessed in this report. As shown in Figure ES-6, across the 12 economies, the highest percentages of direct manufacturing value added retained are found in manufacturing of polysilicon for c-Si PV modules (53%), LDV Li-ion battery cells (38%), wind towers (35%), and wind blades (35%). At the other end of the range, steel, electrolytes and anode materials, and for LDV Li-ion batteries, contributed the least, retaining 22%, 25% and 25%, respectively.

Variations in retention are seen across technologies and intermediates due to a number of factors. If a domestic supply chain for a technology is not well developed within the economy in which the end product manufacturer is located, value added will be a relatively lower percentage of revenue. Larger, diverse economies such as the United States and Japan can generally support more extensive supply chains. Retention can also be affected by the presence of natural resources used in production, unique technology or expertise, or a number of other factors such as currency strength and tariffs.

For example, the direct value added retained by polysilicon manufacturing is higher than other intermediates due to the relatively small number of economies assessed in this report that produce polysilicon and relatively high percentage of direct value added retained within those economies. China led polysilicon production, and value added was 44% of its revenue; China was followed in polysilicon production by the United States (54% retention), Germany (41%), and South Korea (58%). No economy that produced polysilicon retained less than 40% of value added.

Benchmark 2. Clean Energy Trade:

2a. A dynamic trade network connects the 12 economies that manufacture the four clean energy technologies. In total, China, Taiwan, Malaysia, South Korea, and Germany are net exporters of the clean energy technology end products considered. The remaining seven economies are net importers, although this varies by technology and supply chain link.

The clean energy manufacturing trade flow benchmark provides a snapshot of clean energy trade activity across the supply chain. Trade connects the global community and is a significant component of GDP in many economies; balance of trade (exports less imports) is one element of GDP.

Figure ES-7 shows the balance of trade (bar charts) and trade flows (chord charts) for each of the four clean energy technology end products (wind generator sets,[4] PV modules[5], LED packages, and Li-ion battery cells.[6] The chord charts show that PV modules and LED packages are most heavily traded, likely as they are more easily shipped than the other end products. Wind turbines, due to the large size of their key components, are more typically manufactured near their point of use.

The bars in Figures 7A-7D show the clean energy technology end product imports as negative values and the exports as positive values. The balance of trade is noted to the right of the bar. The chord charts show the flow of the clean energy technology end products. The darker tones represent exports, and the lighter tones represent imports. Note that the bar chart includes trade with "rest of world"—other economies not included in this report; the chord chart only includes trade among the 12 economies included in the report. Interactive trade flow charts can be accessed at ManufacturingCleanEnergy.org/Benchmark.

4. A wind generator set consists of a nacelle packaged with blades.

5. Trade data is not disaggregated by module technology (i.e. c-Si PV modules).

6. Trade data is not disaggregated by end use (i.e. LDV Li-ion battery cells).

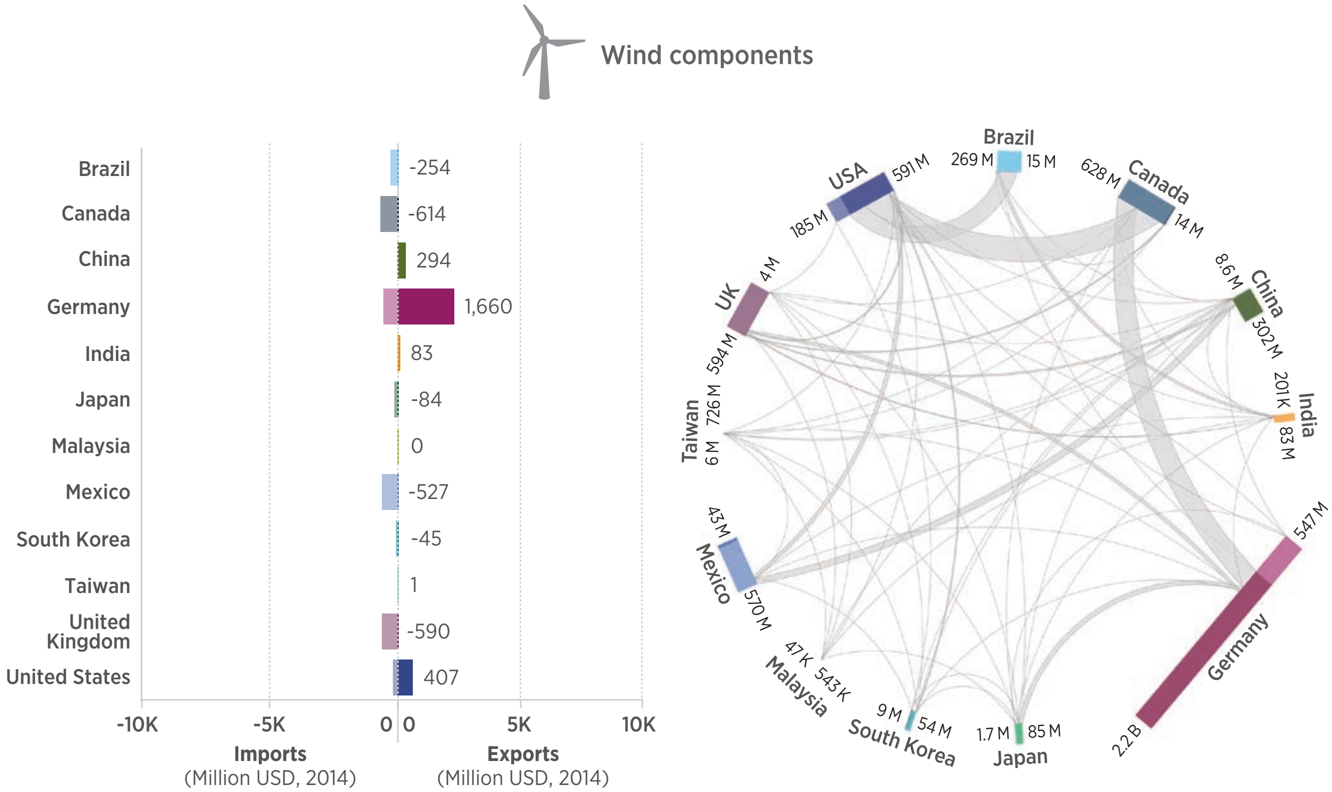


Figure ES-7A. Balance of trade and trade flows for wind generator sets (nacelle and blades), 2014. Darker shades represent exports; lighter shades represent imports.

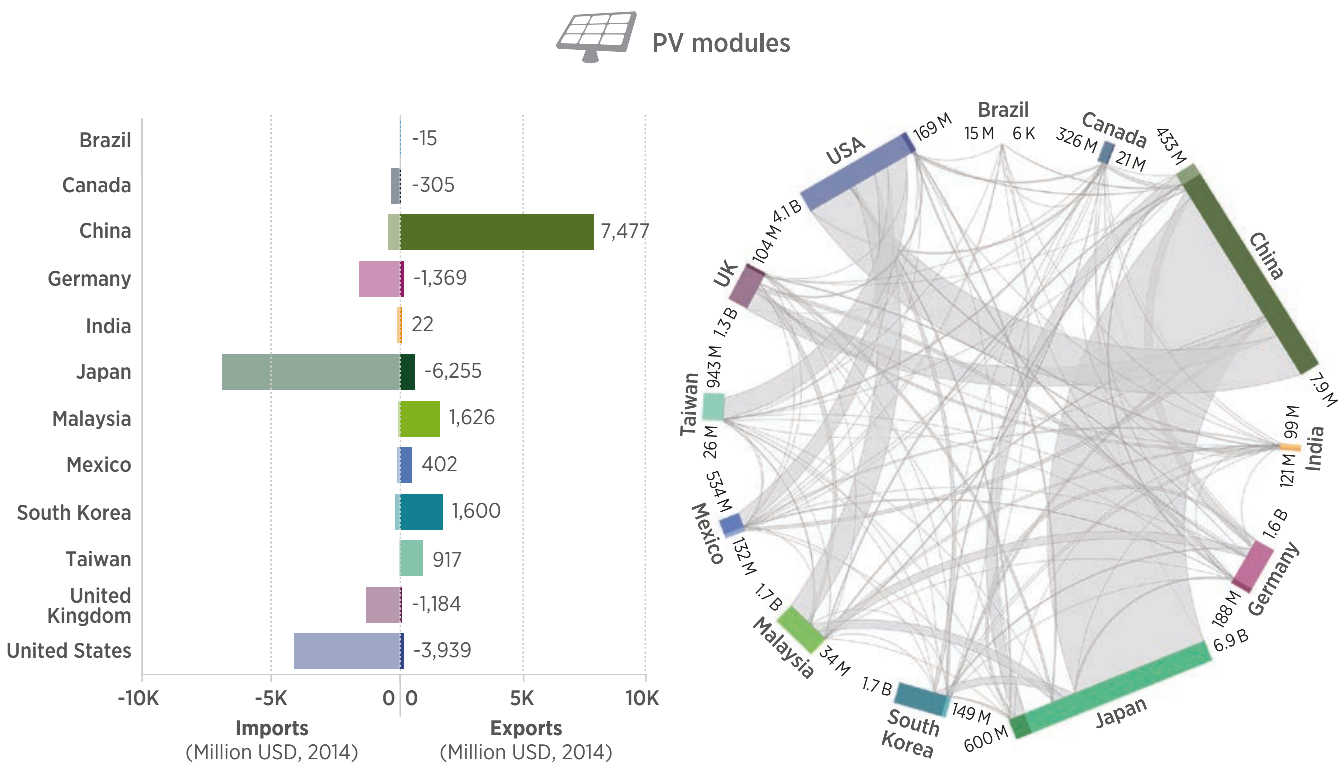


Figure ES-7B. Balance of trade and trade flows for PV modules, 2014. Darker shades represent exports; lighter shades represent imports.

LED packages

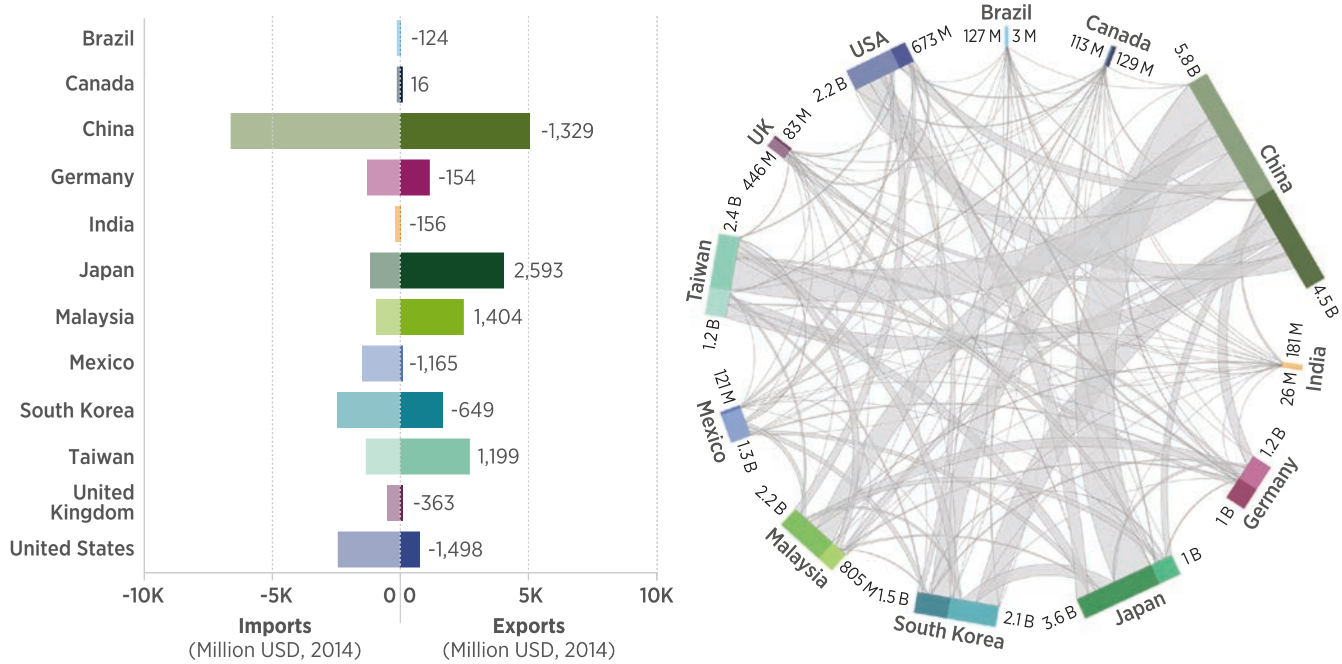


Figure ES-7C. Balance of trade and trade flows for LED packages, 2014. Darker shades represent exports; lighter shades represent imports.

Li-ion battery cells

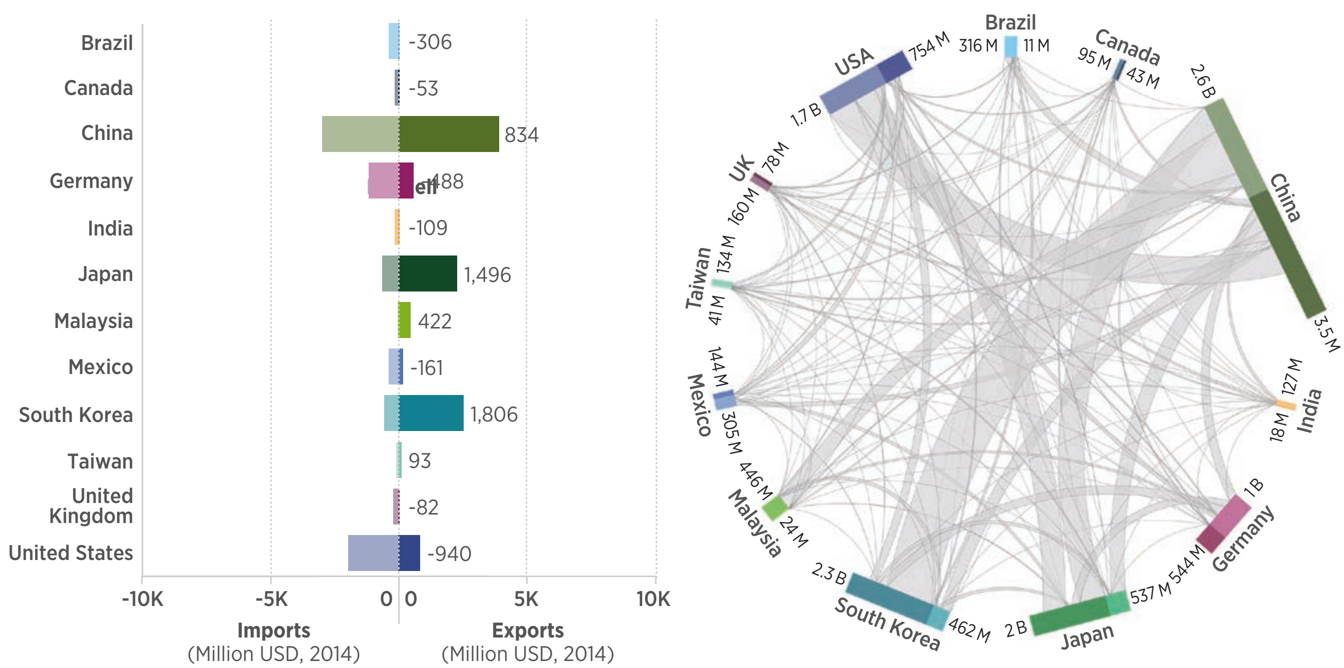
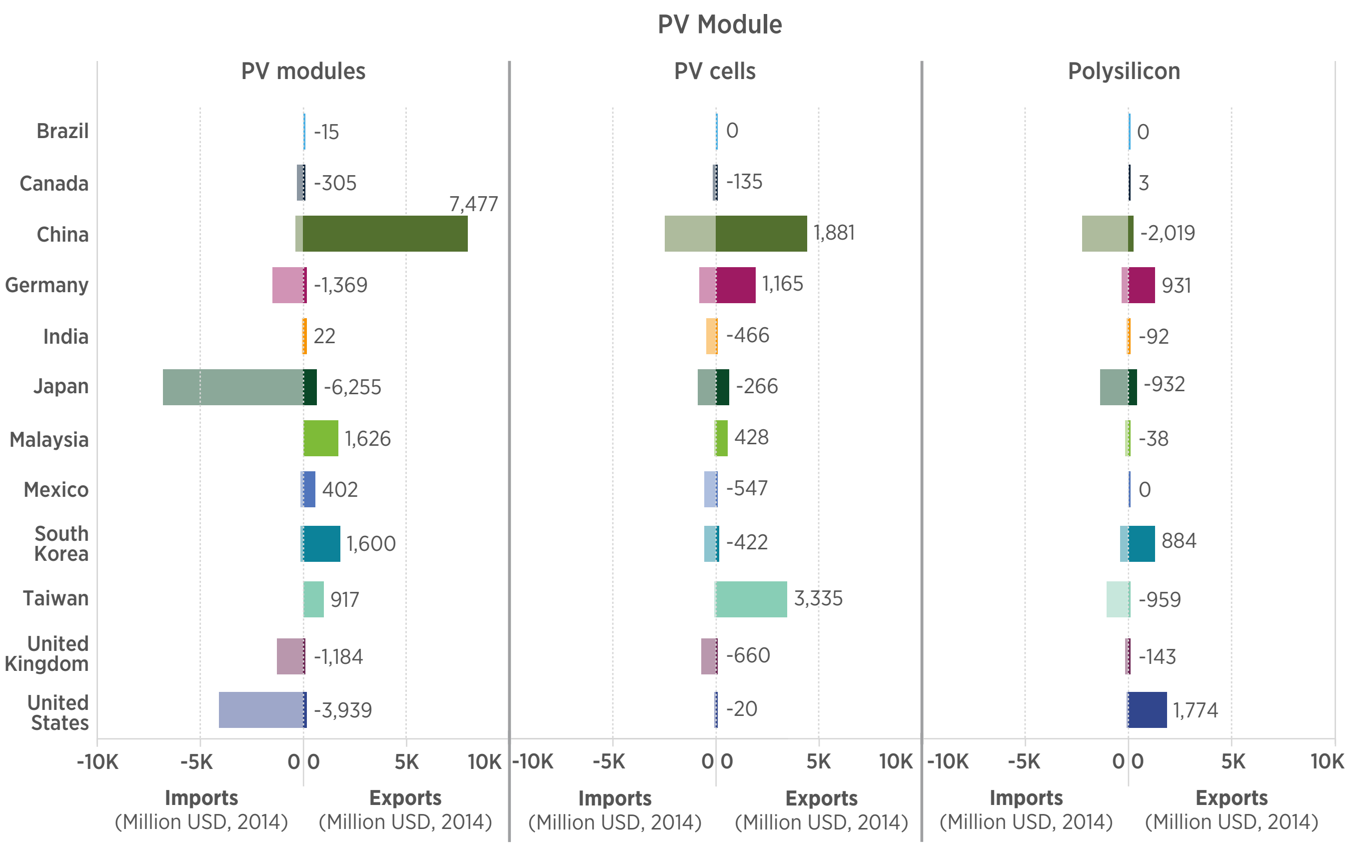


Figure ES-7D. Balance of trade and trade flows for Li-ion battery cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

2b. The end product trade is part of a more complex story. Economies that are net importers of end products may be major net exporters of upstream processed materials and subcomponents of those same technologies. For example, the U.S. is a net exporter of polysilicon but a net importer of c-Si PV modules.

Trade is most easily tracked by identifiable end products but the upstream links in the supply chain are complex, global, and dynamic, thus are more difficult to track accurately. Where we are able to do so, we found considerable economic value of manufacturing to many more economies than just those producing end products. The technology that best illustrates this and has the most available data are c-Si PV modules.

In 2014, the 12 included economies exported more than 31.0 billion USD in PV modules, cells and polysilicon, and imported 28.0 billion USD. China was the largest exporter of cells and modules, exporting 12.3 billion USD in 2014 to Japan and the United States, among others. China and Malaysia accounted for 60% of United States imports, although it is important to note that several of the major solar manufacturers in Malaysia are owned by companies headquartered in the United States and other economies. However, looking up the supply chain, the United States and Germany were the largest exporters of polysilicon at 1.9 billion USD and 1.3 billion USD, respectively, with high positive balance of trade in polysilicon, purchased largely by Japan and China. Figure ES-8 shows the trade flows and balance of trade for PV modules, cells, and polysilicon, illustrating the complexity of manufacturing and trade of clean energy technologies.



Figures ES-8. Balance of trade for PV modules, cells, and polysilicon.

Benchmark 3. Clean Energy Market Size:

The manufacturing of clean energy technologies studied contribute to markets of widely varying sizes, ranging from the $45 billion wind industry to the $2 billion automotive lithium-ion cell industry. Economy specific demand patterns vary across the technologies.

The industries into which each energy technology is deployed are distinct from one another, and are largely driven by specific policies and conditions. Economy-specific demand patterns do not appear to be consistent across the technologies, although China, Japan, and the United States maintain 5% or better market share in at least three of the four industries analyzed.

As illustrated in Figure ES-9, wind and c-Si PV end products make up the largest contribution to demand (in USD) for clean energy technologies across the 12 economies and in combination are roughly 2.5 times greater than that for LED package and more than 13 times greater than that for LDV Li-ion cells, likely in part due to differences in technology market maturity. Demand for LED packages (to be used in manufacturing of a wide variety of products from lighting to televisions) is particularly concentrated, with nearly 100% of aggregate demand coming from only five economies: Japan, South Korea, Malaysia, Taiwan, and China, which is where many of the final consumer products that contain LEDs are assembled. Similarly, LDV Li-ion cell demand is also fairly concentrated, with 95% of aggregate demand located in five economies: the United States, Japan, Germany, China, and the United Kingdom, which are leading automotive manufacturers. Wind turbine component and c-Si PV module demand is less concentrated, though a small number of economies in both sectors still constitute a disproportionate share of total global demand.

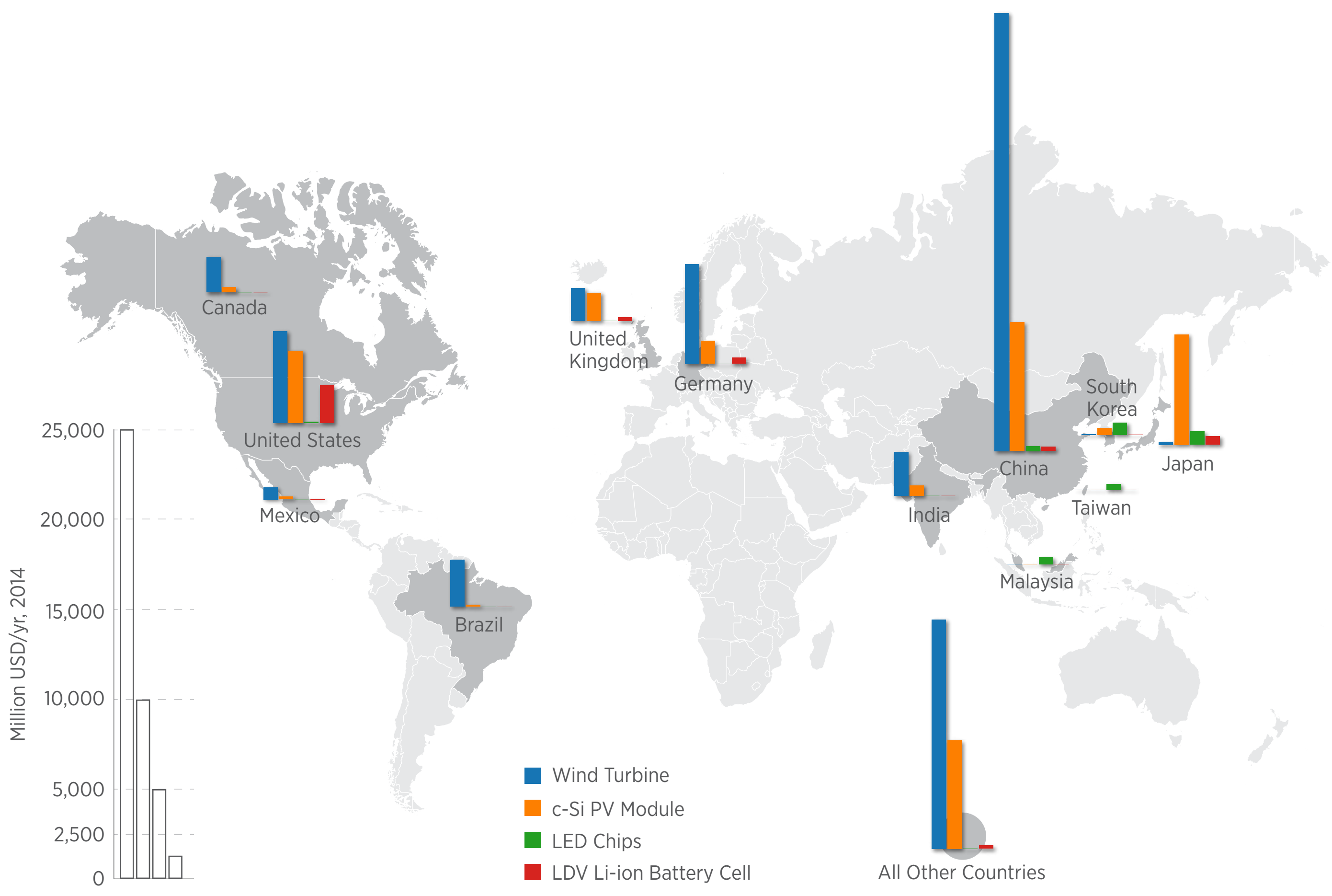


Figure ES-9. Market size of four clean energy technologies for 12 economies, 2014

Benchmark 4. Clean Energy Manufacturing Capacity and Production:

4a. Production of wind turbine components and c-Si PV modules is more concentrated than production of LED chips and LDV Li-ion battery cells. Wind components are typically made in the same economies that have high demand, but manufacturing and demand for c-Si PV modules, LED chips, and LDV Li-ion battery cells are less coincident.

Within each industry, the alignment of geographic distribution of manufacturing capacity with the geographic distribution of demand varies significantly. The notable exception is the wind industry, where demand and manufacturing capacity are co-located on a regional basis. Figure ES-10 compares demand and production for the four clean energy technology end products.

Both wind turbine and c-Si PV module production is heavily concentrated in China, where they are also deployed in large numbers. Wind turbine production outside of China occurs

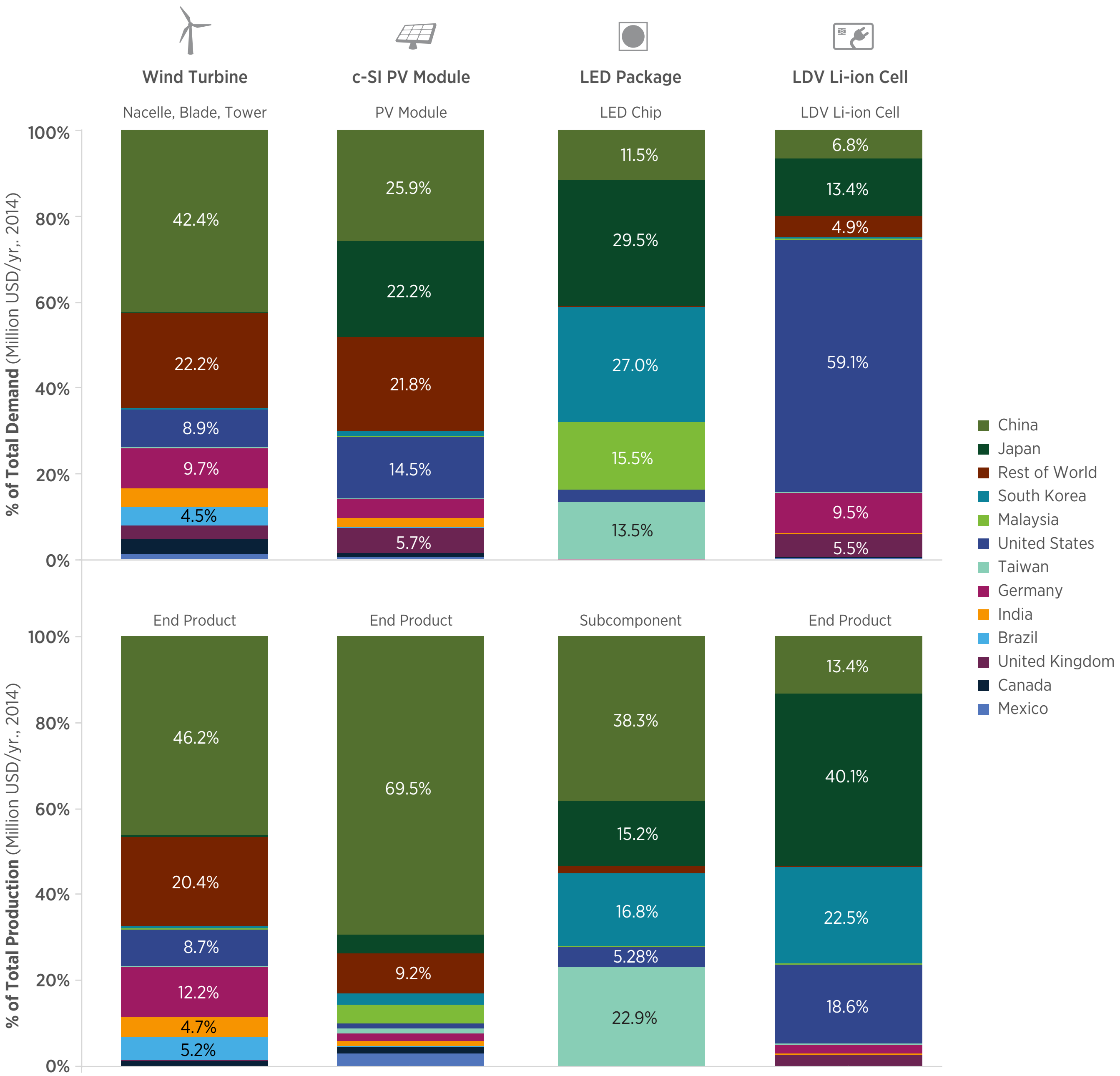


Figure ES-10. Market demand and production shares for four clean energy technology end products. Note: LED chip (subcomponent), rather than LED package (end product) data reported, due to lack of economy-specific LED package production data.

Demand and Production values are shown as shares of the aggregate demand and production, respectively, of the 12 economies assessed.

mostly in the United States, Brazil, India, and Germany. Wind turbine manufacturing is typically located close to demand due to transportation logistical challenges associated with the size and weight of the components. C-Si PV module production outside of China is dispersed across all but two of the economies included here, with Japan and Malaysia hosting the next largest shares of module production. C-Si PV has the most mis-alignment of production to demand. Production of both LED Packages and LDV Li-ion battery cells is more globally distributed than production of c-Si PV modules, yet practically all global production for these end products occurs in only four or five economies. LED Packages are produced mostly in Japan, South Korea, Malaysia, Taiwan, and China, while LDV Li-ion cell production is concentrated in Japan, South Korea, the United States, and China. In general, different supply chain links for each technology appear to be nationally co-located. Countries hosting significant shares of end product production often, although not always, produce a commensurate share of upstream subcomponent and processed materials.

4b. Across the four clean energy technologies evaluated, in 2014 there was generally an excess of manufacturing capacity, relative to global demand.

Manufacturing production and capacity data suggest excess capacity existed across the 12 economies assessed in 2014 (Figure ES-11). The average manufacturing capacity utilization was estimated at 62% for wind turbine

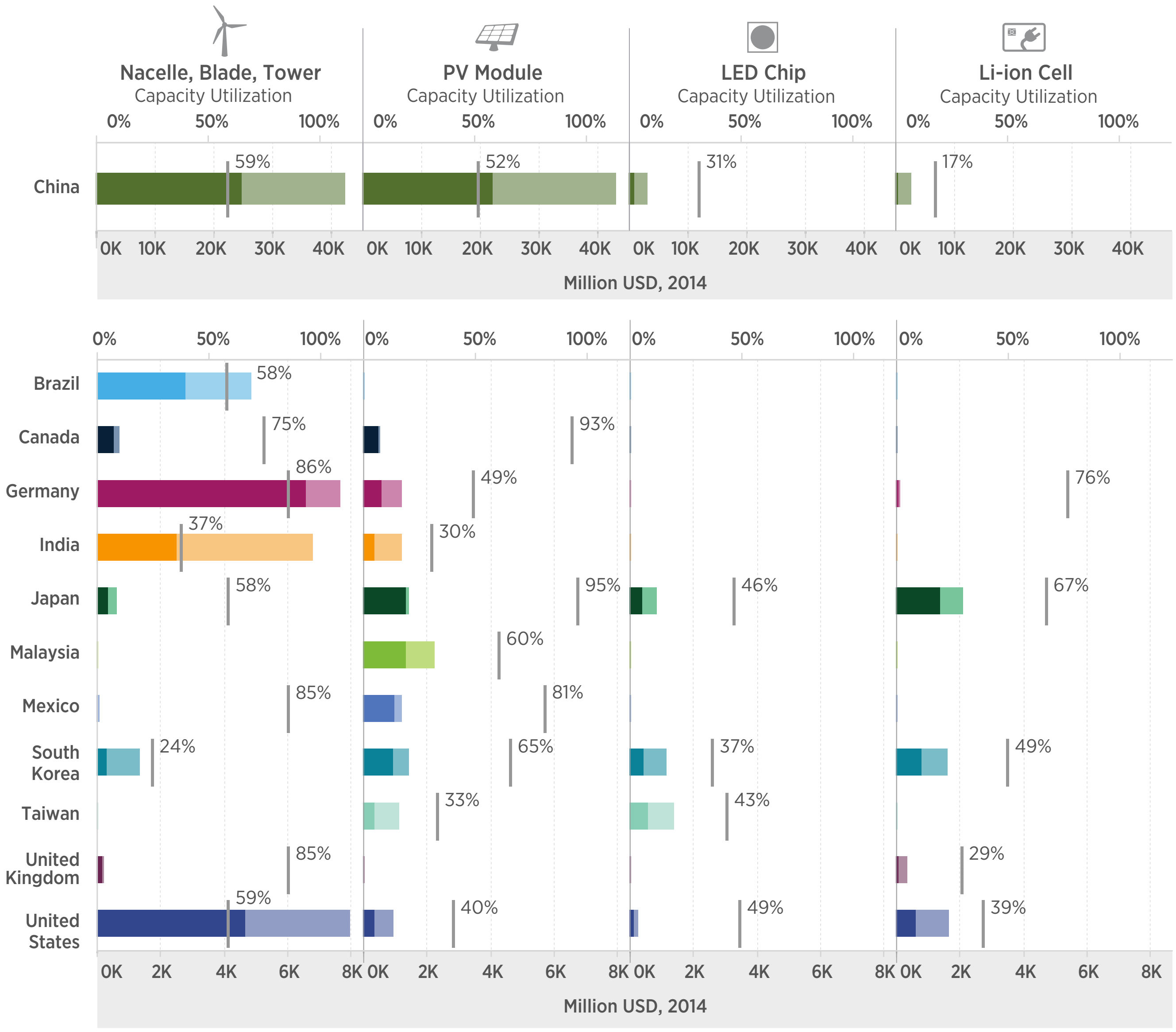


Figure ES-11. Production and production capacity utilization for four clean energy technology end products. Note: LED chip (subcomponent), rather than LED package (end product) data reported, due to lack of production data.

Each bar shows the production revenue for the end product (darker shade) and the production value of unused manufacturing capacity (lighter shade) based on the lower horizontal scale. The line and numerical value show the capacity utilization rate based on the upper horizontal scale.

components, 55% for c-Si PV modules, 37% for LED chips, and 41% for LDV Li-ion cells. Excess capacity can be used to meet potential demand growth from increased technology adoption. However, without increased demand, persistent excess capacity can place downward pressure on pricing.

The balance of trade (exports less imports) metric shown earlier is influenced by production capacity, capacity utilization, and domestic demand for manufactured products. If domestic demand exceeds domestic production, an economy's balance of trade will be negative. Conversely, if domestic production exceeds domestic demand, the balance of trade will be positive.

Conclusions

The current state of clean energy trade reflects the cumulative dynamics of a high-growth decade in which both markets and manufacturing have grown significantly within an increasingly complex set of policy environments. Strong domestic markets have not necessarily been supplied by domestic manufacturing, particularly markets for those technologies that benefit from economies of scale and where incentives for manufacturing investment or output have been adopted, and markets for technologies where transportation was not a determining factor for manufacturing location, such as PV modules, Li-ion battery cells and LED packages.

The U.S. situation is notable, as clean energy markets have been particularly strong and are served by both domestic and imported end products. The United States is one of the top five manufacturing economies globally and retains the highest amount of manufacturing value added of the technologies evaluated. Even though the United States is a net importer to meet its large demand for the technologies evaluated, some U.S. clean energy technology manufacturers are net exporters of components upstream in the supply chains. China stands out as an example where policies have been implemented to support both domestic markets and the expansion of domestic manufacturing to serve both domestic and export markets. In Japan, both these situations are apparent for specific technologies: the country's strong domestic market for PV modules is served with significant imports, while its LED package manufacturing serves both its domestic and export markets.

For the clean energy technologies covered in this report and many others, technology innovation is anticipated to continue to drive relatively rapid turnover of technologies and associated manufacturing capacity. Such innovation creates significant opportunities to attract manufacturers that can serve domestic markets, compete effectively in other markets, and displace incumbent technologies.

Manufacturing activity and investment in new manufacturing facilities respond to a number of key drivers, including but not limited to demand in domestic markets, demand in export markets, and investment incentives. Domestic markets can be an initial driver for domestic manufacturing, although as deployment increases and prices fall, there is no guarantee that manufacturing will be geographically aligned with demand, absent other policies or economic drivers. With the right combination of skilled labor and investment, manufacturing for export can become a second key driver, sometimes even without a local market. Irrespective of manufacturing, localized clean energy technology deployment as well as multinational corporate headquarters and research facilities both generate significant value in their own right. Increasing deployment of clean energy technologies provides manufacturers with a more stable demand and enables investment that drives down prices through economies of scale.

Our results also emphasize the importance of policymakers having a deep understanding the entire supply chain of clean energy technologies, because even in cases where the end product manufacturing is concentrated, the upstream components and materials may come from many economies. Due to the complex influences across many sectors of national and global economies, considering the entire development, manufacturing, and deployment supply chain in investment and incentive decisions could be important.

Manufacturing of clean energy technologies is a global enterprise that changes in response to market forces and technology advances in new end products and also in advanced manufacturing equipment, processes, and materials used to generate these end products. Deeper knowledge of the product supply chains and market volumes can inform industry decisions related to the location of manufacturing facilities for extracting and processing raw materials, making the required subcomponents, and assembling the final product. This knowledge can also inform decisions around R&D and international trade.

We look forward to continuing to benchmark the four technologies assessed in this report, increasing the detailed understanding of their value chains, as well as broadening the scope of our benchmark efforts to include other commercial and emerging clean energy technologies.

Table of Contents

List of Figures

List of Tables

1 | Introduction

The Clean Energy Manufacturing Analysis Center (CEMAC) analysts at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) prepared this report in order to provide common reference points—benchmarks—to help government and industry describe and assess the global state of clean energy manufacturing.

Context and Purpose of Report

The energy market is undergoing a fundamental transformation, becoming cleaner, more efficient, and more decentralized. Consumers, businesses, and utilities are increasingly adopting clean energy technologies, including solar panels, wind turbines, LED lighting, and electric and hybrid vehicles. This adoption is both the result and the source of technology advancements and manufacturing improvements that have reduced costs and improved performance.

Manufacturing of these clean energy technologies exemplifies the dynamic and globalized state of manufacturing, including complex supply chains and markets. For example, solar panels "Made in the USA" may contain processed materials from Africa and the Middle East, subcomponents from Asia, and intellectual property from Europe.

In this report, CEMAC defines a methodology for evaluating clean energy technology manufacturing, applies the methodology to four technologies and a dozen leading manufacturing economies, and from that assessment, creates four benchmarks for understanding and comparing the impact of manufacturing of the four technologies. We assess manufacturing impacts for end products and the key components of the manufacturing supply chain. Government and industry decision makers may use this report to inform energy policy, trade policy, and investment strategies.

As a preliminary assessment, this report establishes a method for measuring these benchmarks. Over time, our goal is to describe trends within the sectors benchmarked here, and to extend these measurements to additional sectors of the clean energy economy.

Scope of Report

The supply chain of a clean energy technology includes several links, each of which creates economic value. For example, a wind energy project supply chain could include:

- Development: Wind project development activities lay the foundation for project success and include resource assessments, environmental impact assessments, navigating approval processes, and transmission and distribution infrastructure planning.
- Manufacturing: Extracting and processing raw materials into the thousands of subcomponents that a wind turbine comprises provides economic benefits to the economies involved in producing these products.

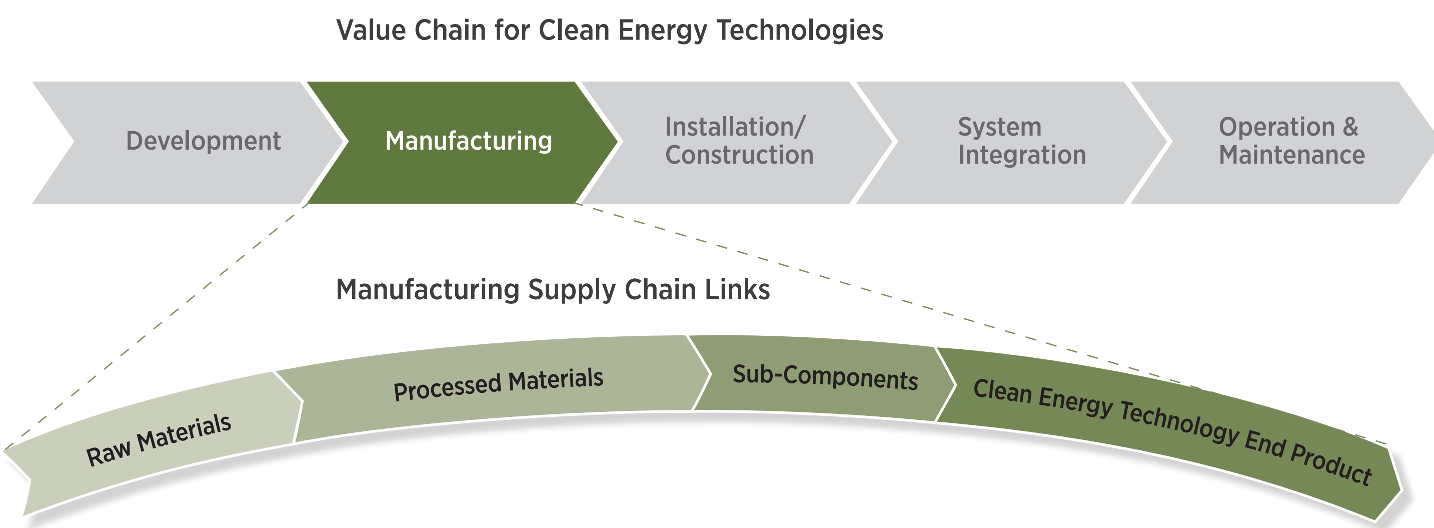


Figure 1-1. Value chain with manufacturing links for clean energy technologies

- Installation/Construction: For wind projects, installation and construction involves assembling the wind turbine components—nacelle, blades, tower—at the project site.
- System Integration: Grid connection of the wind turbine involves engaging local utilities and regulatory authorities to understand local requirements and develop grid connection agreements and integration strategies.
- Operation and Maintenance: Wind turbines are normally operated over a lifetime of more than 20 years, so operation and maintenance offers a long-term economic benefit.

This analysis focuses on a single aspect of the supply chain: manufacturing. We then examine the supply chain of manufacturing (Figure 1-1) in terms of four links: raw materials, processed materials, sub-components, and end product.

We describe the manufacturing supply chain of four clean energy technologies: crystalline-silicon (c-Si) photovoltaic (PV) modules, wind turbine components (nacelle, blades, and tower), light emitting diode (LED) packages for a range of consumer applications including lighting, and automotive lithium-ion battery (Li-ion) cells. The selected technologies span the energy ecosystem, including electricity production, energy storage, energy efficiency, and transportation. Furthermore, the selected technologies are in various stages of commercialization, which helped us test the benchmark methodologies.

We look at the manufacturing and trade landscape for these four technologies in 12 economies, selected because they play a significant role in the manufacturing of the selected technologies. Finally, we established four common points of comparison—benchmarks—to provide a standardized and objective basis for (1) comparing key aspects of clean energy manufacturing on a global and national basis, and (2) tracking changes as markets and manufacturing processes evolve.

CEMAC's benchmark report provides important insights about the production of select clean energy technologies, but it is not intended to represent the full clean energy technology space. The process for selecting the technologies and economies and establishing the benchmarks is described in the Framework section.

The scope of the report was also defined in part by availability of reliable, credible information to support the required analytical modeling. While information about the final products is often available, the upstream data are often intertwined with much larger markets and difficult to extract. The data sources and the assumptions made to estimate these data can be found in each section with the specific benchmarks.

2 | Framework

The framework establishes the crosscutting features for all the benchmarks, including specific definitions, taxonomy of the supply chain links for the development of the benchmarks, and screening criteria for selection of technologies and economies to include in the benchmark report. The four benchmarks and the methodologies used to establish each are described in this section. More detail is provided in a separate methodology document (CEMAC 2017). The base year for the benchmark analysis is 2014, the most recent year for which reliable, comprehensive data are available. We draw from public and proprietary sources, primary and secondary sources.

Clean Energy Definition and Technology Selection

CEMAC defines clean energy technologies as those that produce energy with fewer environmental impacts than conventional technologies, or that enable existing technologies to operate more efficiently, consuming fewer natural resources to deliver energy services. Clean energy technologies may include renewable energy, clean advanced fuels, and energy efficiency technologies for electricity generation and sustainable transportation. CEMAC conducts analysis on technology end products, components, and enabling materials and techniques; however, the focus of the CEMAC benchmark analysis is on the end products.

With this broad definition, many clean energy technologies could be included in the benchmark. This report covers a small but important subset of clean energy technologies: c-Si PV modules, wind turbine components, LED packages, and Li-ion battery cells for automobiles. Sufficient information about the technologies is available to enable high-quality analysis. The criteria for including clean energy technologies in the benchmark report are:

- Completeness of manufacturing supply chain
- Manufacturing cost analysis by the National Renewable Energy Laboratory, Joint Institute for Strategic Energy Analysis, or CEMAC is complete or in progress
- Global market size and/or projected growth sufficient to be commercial or near-commercial
- Potential impact on carbon intensity or carbon efficiency
- Opportunity available for innovation or rapid scale up within manufacturing supply chain.

The economies where clean energy technologies—and the contributing subcomponents and materials along the supply chain—are sourced and manufactured vary by technology. Selected based on an assessment of the market size, manufacturing capacity and production across the manufacturing supply chain, and data availability for each technology, these economies are covered in the report:

- Brazil
- Canada
- China
- Germany
- India
- Japan
- Malaysia
- Mexico
- South Korea
- Taiwan
- United Kingdom
- United States.

Manufacturing Supply Chain and Technology Alignment

To facilitate communication of benchmark results across a diverse range of clean energy technologies and manufacturing processes, CEMAC established a consistent, high-level process flow outlining the value-added links in the manufacturing supply chain. CEMAC describes the four links of the manufacturing supply chain as:

- **Raw materials**: A basic raw or unprocessed material is one that is mined, extracted, or harvested from the earth. Examples include raw biomass and iron ore. In this link of the supply chain, value added comes from extracting, harvesting, and preparing raw materials for international markets in substantial volumes.
- **Processed materials**: A processed material is one that has been transformed or refined from a basic raw material as an intermediate step in the manufacturing process. Processed materials include steel, glass, and cement. In this link of the supply chain, value added comes from processing raw materials into precursors that can be more easily transported, stored, and used for downstream subcomponent fabrication.
- **Subcomponents**: A subcomponent is a unique constituent part or element that contributes to a finished product. Clean energy technology examples include generators for wind turbine nacelles and c-Si wafers for PV modules. In this link of the supply chain, value added comes from fabricating processed materials into subcomponents that can then be assembled (with other subcomponents) into end products.

Raw Materials	Processed Materials	Sub-Components	Clean Energy Technology End Product
Silica, Silver	**Polysilicon,** Silver Paste, Glass	**C-Si PV Wafer, C-Si PV Cell,** Frame, Encapsulant	**C-Si Solar PV Module**
Iron, Neodymium, or Dysprosium Ores	**Steel,** Fiberglass, Carbon Fiber, Neodymium and Dysprosium Alloys	Permanent Magnets, **Generators,** Gear Assemblies, Steel Components	**Wind Turbine Components: Blades, Tower, Nacelle**
Lithium, Cobalt, Nickel, Graphite Ores	**Cathode Materials, Anode Materials, Electrolytes**	**Separators,** Housings, Metal Foils, Tabs	**Light Duty Vehicle (LDV) Li-ion Battery Cell**
Gallium, Indium, Yttrium Ores	**Sapphire Substrates,** Trimethyl Gallium (TMG), Trimethylindium (TMI), YAG Phosphors	**LED Chips**	**LED Package**

Figure 2-1. Clean energy manufacturing supply chain links and examples (bolded items are included in the analysis)

- **Clean energy technology end product**: The end product is the finished product of the manufacturing process, assembled from subcomponents and ready for installation. Clean energy examples include c-Si PV modules and LED packages. In this link of the supply chain, value added comes from assembling subcomponents into the final end product.

This structure facilitates communication of benchmark results and the examination of clean energy data across technologies, and provides flexibility to address the significant manufacturing differences for each clean energy technology. Alignment of the technologies in this report with the supply chain framework is illustrated in Figure 2-1. To make this exercise manageable, we selected specific materials, intermediates, and subcomponents for each link based on an assessment of: raw material constraints, uniqueness or role as enabling process or product, global imports and exports, impact on overall cost, and contribution to quality. In this analysis, we benchmark processed materials, subcomponents, and end products. For relevant raw materials, we lacked sufficient data, particularly the share devoted specifically to clean energy manufacturing, to permit robust analysis.

Benchmarks

The four benchmarks and their associated goals are summarized in Table 2-1. The benchmarks provide unique insights into the value added in each link in the manufacturing supply chain.

Methodologies

A primary goal of this analysis was to develop new methodologies to reliably establish each benchmark.

Manufacturing Value Added

We estimate manufacturing value added from clean energy technologies using a combination of CEMAC cost analysis, market data, and social accounting data from the Organization for Economic Cooperation and Development (OECD) Structural Analysis (STAN) Input-Output (I-O) database.[7] I-O models can be used to estimate the value added of manufacturing commodities when comprehensive data about the commodities and supply chain are lacking (Miller and Blair 2009). For input to the STAN I-O database, we used CEMAC manufacturing cost analysis for estimates of the critical costs incurred in the manufacture of a given clean technology along the supply chain and attributed to a specific point of origin.

Table 2-1. Summary of CEMAC Benchmarks and Goals

Benchmark	Description	Key Goal
Global Clean Energy Manufacturing Value Added	Value added consists of labor payments, gross operating surplus (profit, payments for capital and payments to investors), and taxes, and can be a measure of gross domestic product (GDP). For each technology covered, we estimate manufacturing value added by economy for each link of the manufacturing supply chain. This information is reported and aggregated by economy within each technology area and across all technology areas.	Comprehensive estimate of clean energy manufacturing contribution to national and global economies
Global Clean Energy Manufacturing Trade Flows	Trade flows measure the balance of trade, i.e., the amount of goods that one economy sells to other economies (exports) minus the amount of goods that an economy buys from other economies (imports). We estimate the total international trade flows and net imports and exports by and between economies are estimated for each technology covered, for each link of manufacturing supply chain, and in aggregate.	International snapshot of clean energy trade activity across the supply chain
Global Clean Energy Market Size	For each technology covered, the total end-use global market demand for manufactured clean energy technologies by economy is estimated and aggregated across technology areas.	Relative importance of clean energy technologies to an economy
Global Manufacturing Capacity and Production	For each technology covered, the capacity and production in each link of the manufacturing supply chain is estimated by economy.	Clean energy manufacturing capacity and production relationships around the world

7. Further information about the OECD STAN I-O database, including the data used in the benchmark study, can be found at http://www.oecd.org/sti/ind/stanstructuralanalysisdatabase.htm.

The social accounting data in the STAN I-O database, like other I-O models, characterizes a nation's economy in terms of purchases (inputs) and sales (outputs), where every input purchased by a particular industry is an output produced by another. Because I-O models account for all sales and purchases, they provide a comprehensive view of economic activity required and total value added for modeled scenarios.

Value added has direct and indirect components. Direct value added is the value added from a given producer within a given economy. Indirect value added or economic ripple effect is the value added from all the associated supply chain activity necessary to support the given producer within the given economy. For example, when looking at value added from wind generator manufacturing in China, direct value added would come from the wind generator manufacturers themselves. Indirect value added would come from businesses and industries that supply goods and services to these manufacturers. These might include copper wire manufacturers, legal service providers, accounting service providers, or natural resource extraction companies.

Each technology has an end product (or end products) comprised of subcomponents. In c-Si PV, for example, polysilicon is used to produce wafers, wafers are used to produce cells, and cells are used to produce modules. Indirect value added estimates include impacts from the supply chain for each component. Thus, indirect value added estimates for wafers would include value added from polysilicon production. Value added estimates for polysilicon, however, are estimated and presented separately. If the value added estimates in this report for wafers and polysilicon were aggregated, then value added from polysilicon would be double-counted because it is in both estimates. The total value added estimates in this report reflect value added across all subcomponents in aggregate without counting them twice rather than each subcomponent by itself. Therefore, total value added is always less than the sum of value added from subcomponents.

Direct value added estimates do sum to totals because they solely include the component in question. Direct value added from polysilicon production only includes polysilicon. Direct value added from wafer production only includes wafers.

Trade Flows

Trade flows show the interconnectedness of the global community as economies sell and purchase goods and services to and from one another. In addition, the balance of trade (exports less imports) is a component of GDP along with domestic consumption, investment, and government expenditures.

Trade flow data for the benchmark report come from a number of sources. The United States International Trade Commission (U.S. ITC) provides detailed import and export data for the United States. Global trade flow data comes from the International Trade Centre (ITC).[8]

Table 2-2 shows six-digit Harmonized System (HS) codes for the technology supply chains covered in this analysis. Codes may go up to 10 digits, but they are only consistent internationally at the six-digit level.

Table 2-2. Six-Digit Harmonized System Codes for Select Clean Energy Technologies.

Technology	Six-Digit HS Code	Description
LEDs and PV modules and cells	854140	This category includes all photosensitive semiconductors.
Polysilicon	280461	Silicon Containing By Weight Not Less Than 99.99 Percent Of Silicon.
Li-ion batteries	850760	All rechargeable Li-ion batteries
Wind generator sets	850231	Wind generator sets

Data source: http://www.cybex.in/HS-Codes/Electrical-Machinery-Equipment-Parts-Sound-Chapter-85.aspx

8. For more information about the U.S. ITC, see https://www.usitc.gov/ and http://trademap.org.

It is not necessary to specify beyond the six-digit level for polysilicon or wind generator sets. In 2014, none of the economies studied in this report distinguished Li-ion batteries for vehicles from the broader category of all rechargeable Li-ion batteries. The U.S. ITC began making this distinction for imports in 2015. Many economies do differentiate between different types of photosensitive semiconductors. Information about how trade data were disaggregated for this report is available in the CEMAC methodology report (CEMAC 2017).

Countries may be both importers and exporters of different clean energy manufacturing products. This is because these products are not necessarily homogenous. Li-ion batteries, for example, can be for consumer electronics or vehicles. An economy may import one while exporting the other. Products can also be imported, assembled into another product that is still classified within the same trade code, and then exported.

Country-specific production and demand data are used to provide additional insights on trade of clean energy technologies along the supply chain. Some commodities show trade information that differs from production data. For example, production data only shows Brazil producing wind products, yet trade data shows Brazil exporting small amounts of LEDs and PV products (although imports are much greater). These variations could occur for a number of reasons. Businesses may be repackaging and exporting imported products, or data may not have been reported correctly by businesses or host economies.

Market Size, Manufacturing Capacity, and Production

The market benchmarks of global market size, manufacturing capacity, and production can help determine the present and future direction of global clean energy manufacturing. These benchmarks are the fundamental measures used in assessing supply, demand, and industry dynamics.

- **Market size, or market demand**, is an estimate of the amount of a specific product or service that is sold within a defined period of time (annually in this report), and is typically expressed in units of product volume (e.g., megawatts of PV modules) and in terms of monetary value (e.g., U.S. dollars (USD)). Value is the product of the volume and the estimated average global selling price of the product or intermediate.
- **Manufacturing capacity** refers to the amount of product that could be produced in a given time period by the physical plants and other necessary infrastructure (e.g., gigawatt-hours of Li-ion cells per year).
- **Production** is the actual amount of a product manufactured (e.g., number of LED packages per year) during a given time period (annually in this report).

The units used to report demand, manufacturing capacity, and production volumes vary across industries and along the manufacturing supply chain. For example, raw materials like polysilicon are commonly reported by weight in metric tons, or dollars per kilogram (kg), whereas end products are often described by unit of power, or watts. We used engineering estimates to convert the supply chain intermediates into a single volumetric unit for each technology. In addition, although manufacturing capacity and production are not commonly reported in terms of monetary value, we estimated the monetary value of capacity and production by applying estimates of unit prices. Making this estimation allows comparison across technologies and provides input for the value added benchmark based on production value of each technology and intermediate.

Market size, manufacturing capacity, and production data for the selected clean energy end products were collected from existing secondary sources, which generally highlight the economies and regions that together make the largest contributions to the global market or manufacturing capacity. Where available, we used actual production data for each subsequent downstream intermediate product to estimate market demand for key intermediate products within an industry. However, standard secondary sources lack this level of data granularity, especially for smaller industries (LED packages and Li-ion cells). When data were not available, the demand for intermediate products was approximated by assuming that all elements of the supply chain are in balance and that no changes in inventory occur within the supply chain. Thus, the production volume of the end product is equivalent to the demand for each upstream intermediate product in units normalized to end product volume units and 2014 USD.

Data Confidence

This study provides a unique perspective of the clean energy manufacturing value proposition. The data needed to estimate the benchmarks at the desired level of disaggregation are not available for all technologies included in the benchmark report. By applying technology-specific engineering assumptions and analysis best practices, along with consultation and review by experts from industry and academia, we estimated benchmark metrics across the manufacturing supply chain. However, our level of confidence in data reported here varies.

Details of the data confidence and specific assumptions used for each technology are provided in CEMAC's Benchmark Methodology Report (CEMAC 2017). The summaries suggest research opportunities to fill data gaps and strengthen benchmark metrics over time.

BENCHMARKING CLEAN ENERGY MANUFACTURING by Technology

3 | Benchmarking Clean Energy Manufacturing by Technology: Overview

Value Added Benchmark Findings—By Technology

Crystalline Silicon PV Modules

- Solar PV manufacturing contributed total value added of 27.2 billion USD across economies. 12.5 billion USD of this was direct and 14.7 billion USD was indirect.
- China captured nearly 70% of total value added with 18 billion USD (7 billion USD in direct value added and 11 billion USD in indirect value added). Japan (2.1 billion USD in total value added) and Taiwan (1.5 billion USD) retained the second- and third-highest shares of global value added from c-Si PV.
- In the United States, polysilicon production is the largest contributor to value added in PV manufacturing, supporting 0.8 billion USD, which is more than 60% of PV value added.

Li-ion Battery Cells

- In 2014, Li-ion batteries for vehicles produced 3.1 billion USD in value added, of which 1.5 billion was direct and 1.6 billion was indirect.
- Most value added accrued in Japan (1.3 billion USD of the 3.1 billion USD global total). The United States (0.6 billion USD) and China and South Korea (0.5 billion USD each) followed. Value added by all other economies combined was less than 150 million USD.

Wind Turbine Components

- Wind manufacturing provided a total value added of 32.5 billion USD in 2014. Of this, 13.7 billion USD was direct and 18.8 USD was indirect.
- Nearly 60% of total value added in wind, 19.1 billion USD, accrued in China. Germany (4.8 billion USD) and the United States (3.8 billion USD in value added) were significant producers as well.

LED Packages

- Value added from the production of LED packages was 8.6 billion USD in 2014. Direct value added was 4.8 billion USD; indirect was 3.8 billion USD. Of the technologies covered in this report, LEDs are the only one to show higher direct value added than indirect.
- Japan led LED-manufacturing economies in value added, retaining 3.4 billion USD, about 40% of the total. South Korea (1.8 billion USD) and Taiwan (1.2 billion USD) followed.

Trade Benchmark Findings—By Technology

Crystalline Silicon PV Modules

- In aggregate, the 12 economies we studied were net exporters of PV, with a total positive balance of trade of 3.1 billion USD with the rest of the world. The balance was driven by cell and module exports, with a 3.3 billion USD balance of trade with the rest of the world. Polysilicon showed a negative balance of trade of -199 million USD.
- China led cell and module production with more than 12.3 billion USD in exports and 3.0 billion USD in imports, a net balance of 9.4 billion USD. The largest net importers were Japan (-6.5 billion USD balance) and the United States (-4.0 billion USD balance).
- The United States led polysilicon trade with a 1.8 billion USD balance of trade. No other economy exceeded 1.0 billion USD. China was the largest net importer with a -2.0 billion USD balance of trade.

Li-ion Battery Cells

- Trade data for rechargeable Li-ion batteries show China, South Korea, and Japan maintained the largest balances of trade in 2014 (0.8 billion USD, 1.8 billion USD, and 1.5 billion USD, respectively). The United States and Germany were the most significant net importers (-1.0 billion USD, -0.5 billion USD balances of trade, respectively).
- The subset of LDV Li-ion batteries shows similar trends. The top three net exporters are the same, but differently ordered. Japan had the most significant positive balance of trade in LDV Li-ion cells (0.8 billion USD), followed by South Korea (0.7 billion USD) and China

(0.6 billion USD). The United States, Germany, and the United Kingdom were the largest net importers (-1.6 billion USD, -0.3 billion USD, and -0.1 billion USD trade balances, respectively.

Wind Turbine Components (Generator Sets)

- Global trade of wind generator sets was relatively low compared to the total 45.3 billion USD in production revenue and direct value added of 13.7 billion USD. For generator sets,[9] the 12 economies studied had a combined balance of trade with the rest of the world of 324 million USD.
- Subtracting domestic demand from domestic production across the 12 economies, however, creates a different trade story. In aggregate, the economies included in this report were net importers from the rest of the world for all components: nacelles (-2.1 billion USD balance), blades (-1.4 billion USD balance), generators (-262 million USD balance), steel (-49 million USD balance), and towers (-41 million USD balance).

LED Packages

- Approximately 230 million USD in LEDs were imported, on net, by the 12 study economies from the rest of the world.
- Japan (2.6 billion USD), Malaysia (1.4 billion USD) and Taiwan (1.2 billion USD) were leading net exporters. Seven of the 12 economies were net LED importers, led by the United States (-1.5 billion USD balance), China (-1.3 billion USD balance), and Mexico (-1.2 billion USD balance).

Market (Demand, Manufacturing Capacity, Production) Benchmark Findings—By Technology

Crystalline Silicon PV Modules

- Global c-Si PV module manufacturing is concentrated in China, which built up significant capacity in response to strong global demand. China's capacity build up benefitted from federal, provincial, and local policies and financing incentives.
- The United States hosts a material share of polysilicon production, and has traditionally exported significant amounts of polysilicon to wafer producers in China and elsewhere.
- Trade tariffs (U.S. and European Union import duties on Chinese and Taiwanese cells and modules; Chinese import duties on U.S. solar-grade polysilicon) appear to have impacted global shipments and capacity expansion decisions across the supply chain (Chase et al. 2016, Roselund 2016, Shaw and Roselund 2016, Stromsta 2016, Beetz 2015, Roselund 2014a)).
- China, the United States, Japan, India, and the United Kingdom are forecast to be the largest cumulative PV system installation markets—and thus markets with largest PV module demand—between 2015 and 2020. Each of these markets is subject to incentive policy uncertainty.

Li-ion Battery Cells

- In 2014, Japan, South Korea, and China were home to the majority of manufacturing capacity for Li-ion cells and related intermediate products. The capacity in these economies was originally developed to serve consumer electronics markets.
- With respect to automotive-specific cell manufacturing capacity, the United States was also a major manufacturing nation in 2014, hosting 20% of global manufacturing capacity.
- The United States was by far the largest demand market for LDV Li-ion cells, comprising nearly 60% of total global demand. However, global distribution of demand has shifted in 2015 and 2016, with China being the largest market as of this publication date.

Wind Turbine Components

- China led manufacturing capacity and production across the wind manufacturing supply chain. Most production was consumed domestically.
- China was the largest demand market in 2014, with 23.2 GW (25.6 billion USD) of turbines installed, comprising nearly half of total global demand. The United States was the second largest market, installing 4.9 GW (5.6 billion USD) of turbines.
- Overcapacity exists across the supply chain, but is most pronounced in nacelle manufacturing.

9. A generator set is a nacelle packaged with blades.

LED Packages

- The global market for LED packages used in luminaires is estimated at 7.9 billion USD. Demand for LED luminaires, and thus for LED packages used in luminaires, is driven by policy (regulated phase outs of incandescent lighting) and market forces (decline in LED luminaire prices).
- LED package production is concentrated in Japan and South Korea, which together constituted over 55% of total global package output. China and Taiwan are also significant producers, together comprising another 25% of total global production.
- Between 2015 and 2016, the market entered a period of severe oversupply, with resultant price pressure driving average selling prices down by 30%–40%. Consolidation among manufacturers is ongoing and expected to continue.

4 | Manufacturing Crystalline Silicon PV Modules

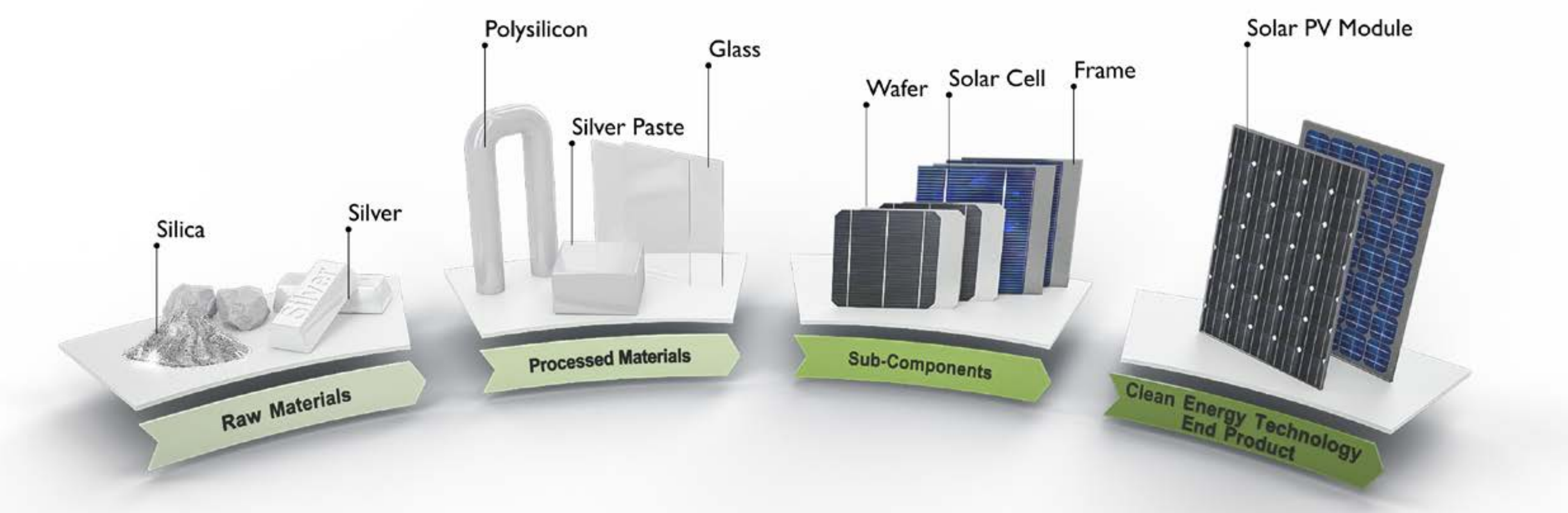


Figure 4-1. How c-Si module manufacturing aligns with CEMAC benchmark framework. Illustration by Josh Bauer, NREL

While the PV industry is well established and rapidly maturing, PV still constitutes only about 1% of global electrical energy production (Henbest et al. 2015) suggesting strong opportunities for growth remain. Crystalline silicon (c-Si) based PV accounts for more than 90% of the PV market (Mints 2016) and is considered to be a mature technology. Figure 4-1 illustrates key parts of the c-Si manufacturing supply chain. Other PV technologies such as CdTe and CIGS thin film-based modules are somewhat less mature, are commercially available via only a limited number of producers, with far lower market share in comparison to c-Si based modules. Previous studies from NREL and CEMAC have explored the cost and competitiveness of solar, from both the manufacturing and system development/installation perspectives.

Manufacture of c-Si Modules

- Global cumulative PV system installed capacity reached 177 GW in 2014, and global annual demand was 43 GW. Average global demand growth is expected to be 12% annually between 2015 and 2020 (NREL estimates using data from BNEF 2015, James 2015, Labastida and Gauntlett 2015).
- Globally, PV attracted 150 Billion USD in investment[10] in 2014, an increase of 25% from 2013 (REN21 2015).
- The global manufacturing network for PV is well established, but opportunities for innovation in manufacturing remain, including cost effective production of advanced cell architectures, polysilicon purity, and other areas contributing to higher cell and module efficiencies.

10. Investments include: governmental and corporate research and development; asset finance of generating projects; and public market and private equity investments in solar companies and funds.

Key Findings

- Global c-Si PV manufacturing is concentrated in China, which built up significant capacity based upon strong global demand, ready access to specialized manufacturing equipment and knowledge, and human capital. Further, federal, provincial, and local policies and financing incentives contributed to the rapid growth of the c-Si PV manufacturing base. (Quitzow 2015).
- The United States hosts a material share of polysilicon production, and has traditionally exported significant amounts of polysilicon to Chinese wafer producers.
- The total value added within each economy analyzed mirrors the share of production within each supply chain link. China accrues the highest levels of value added across the supply chain, with a total of 18.0 billion USD in value contributed to its economy by the production of polysilicon, wafers, cells, and modules. Japan (2.1 billion USD), Taiwan (1.5 billion USD), and Germany (1.4 billion USD) follow China as the top five economies with PV value added. In the United States, polysilicon production is the single largest contributor, supporting 0.8 billion USD—over 60%—of U.S. total value added.
- Major polysilicon net exporters include the United States, Germany, and South Korea. China and Taiwan retain a large share of cell and module manufacturing capacity. Though China is also the largest demand market for modules, the trade data suggest that production far exceeds domestic consumption. Major net importers of cells and modules include Japan, the United States, and the United Kingdom. The ease of shipping PV modules and intermediate products has contributed to the geographic decoupling of manufacturing locales from demand market locations.
- Trade tariffs (U.S. and European Union import duties on Chinese and Taiwanese cells and modules, Chinese import duties on U.S. solar-grade polysilicon) have appeared to impact global shipments and capacity expansion decisions across the supply chain (Chase et al. 2016, Roselund 2016, Shaw and Roselund 2016, Stromsta 2016, Beetz 2015, Roselund 2014a). Major Chinese manufacturers have begun to add new module and cell manufacturing capacity outside of China, in part to serve strong market demand for tariff-free products in the United States and elsewhere. While the United States hosts some of the new capacity, the latest 2016 expansions have mostly been located in (or announced to be located in) Thailand, Vietnam, Malaysia, Korea, Japan, Indonesia, Brazil, South Africa, India, Turkey, Dubai, Germany, the Netherlands, Portugal, Russia, and Canada (Chase et al. 2016).
- In 2014, China also closed a major loophole associated with its 57% anti-dumping duty applied to U.S. solar-grade polysilicon, with the apparent effect of reducing U.S. polysilicon production (Feldman et al. 2016, GTM and SEIA report). While U.S. shipments are trending down, some U.S.-made polysilicon seems to be flowing into China via Taiwan (Shaw and Roselund 2016). Nonetheless, U.S. polysilicon manufacturers have cited Chinese tariffs as a contributor to capacity reductions and expansion cancellations at U.S. polysilicon facilities (Beetz 2015, Shaw and Roselund 2016, Roselund 2014a).
- China, the United States, Japan, India, and the United Kingdom are forecast to be the largest cumulative PV module demand markets between 2015 and 2020. Each of these markets is subject to incentive policy uncertainty.

Value Added

In 2014 the 12 economies covered in this report produced 27.2 billion USD in value added from the production of c-Si PV modules, cells, wafers, and polysilicon. Of this, 12.5 billion USD was direct, coming from the manufacturers themselves. The other 14.7 billion USD was indirect, coming from domestic suppliers of goods and services within each economy.

China was the largest producer of c-Si PV end products and subcomponents, with approximately 43.4 billion USD in revenue generated in 2014. This is much larger than the next largest economy, Taiwan, which generated 3.8 billion USD. Total value added for China was also much greater than other economies, totaling 18.0 billion USD (Figure 4-2). This is followed by Japan (2.1 billion USD), which produced less than Taiwan yet captured a larger portion of production revenue. Taiwan followed Japan with 1.5 billion USD in value added.

Modules provided the highest levels of value added across all economies in this report (14.7 billion USD; figure 4-2).[11] No individual subcomponent exceeds this amount, but the sum of subcomponents (17.7 billion USD) is greater. In the United States, Germany, and South Korea, all among the top five producers of PV, polysilicon was most significant among PV components.

Value added is retained shows a different picture than the absolute levels of value added (See Appendix). In this case China does not have the highest percentages. China is the highest in module, cell, and wafer production revenue and value added, yet retained only 15% of revenue as direct value added. Despite relatively low production, United States module manufacturers retained the highest percentage of revenue as direct value added (65%). Malaysia led all economies in this report in the direct value added retained for polysilicon production revenue at 77%.

Slightly different trends emerge when including indirect impacts. The United States retains more direct and indirect value added across all subcomponents and PV production as a whole: 87% compared to 45%.

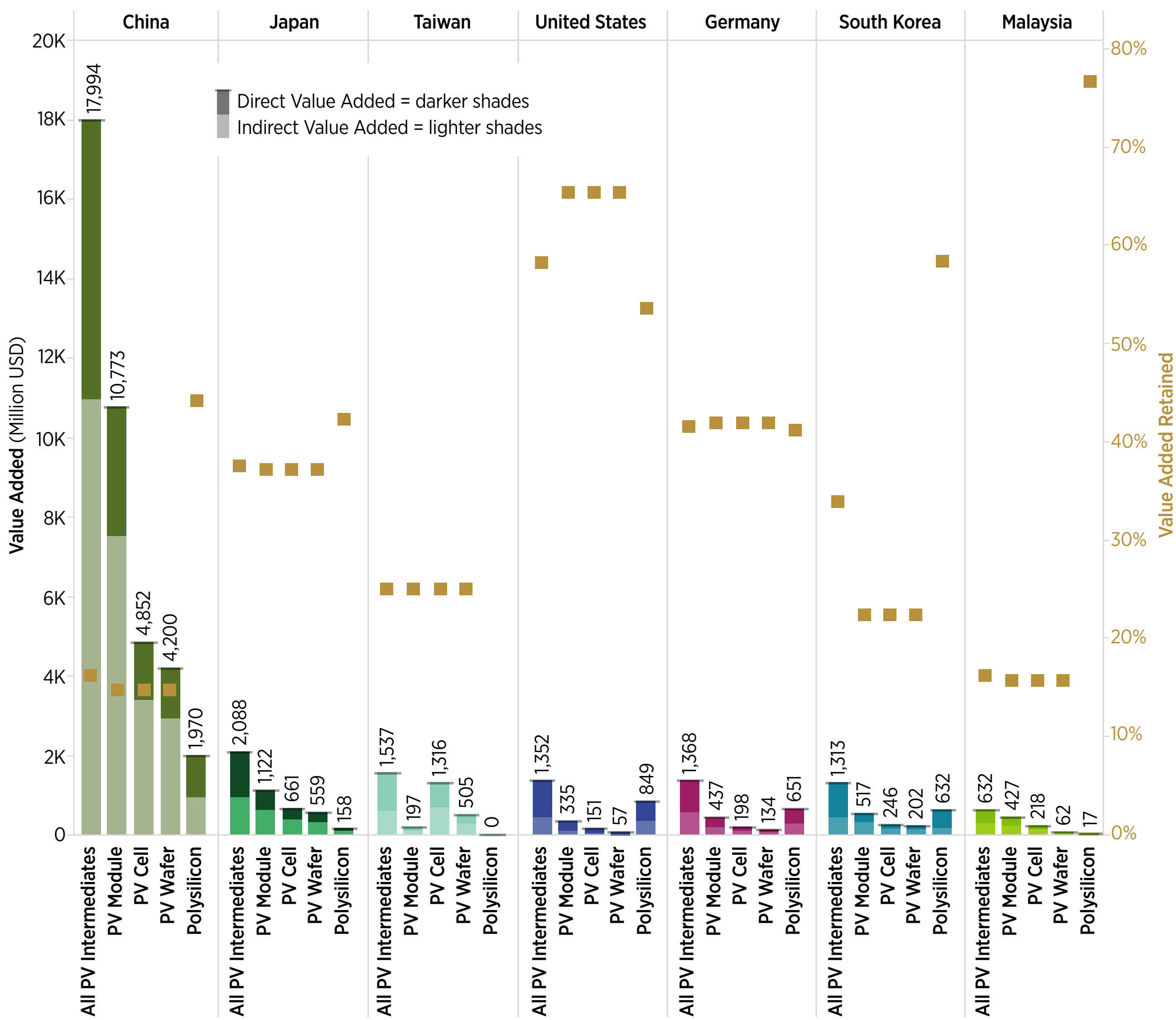


Figure 4-2. Value Added—direct (darker shading) and indirect (lighter shading)—for solar PV, in total and by supply chain link, 2014. Direct value added retained indicated by squares (right axis). See methodology report for data quality discussion.

11. Total value added is adjusted to avoid double counting. Therefore, the total may be less than the sum of all components. We did not make the same adjustments for subcomponents.

Balance of Trade and Trade Flows

In 2014 the included economies exported 30.6 billion USD in polysilicon, cells, and modules and imported 28.0 billion USD.[12] As shown in Figures 4-3 and 4-4, most exports were cells and modules, which accounted for 25.3 billion USD. The remaining 5.3 billion USD was polysilicon. Similarly, cell and module imports totaled 22.0 billion USD while polysilicon was 5.9 billion USD.

China was the largest net exporter (exports less imports) of PV components in 2014, carrying a balance of trade of 7.3 billion USD. Net exports of cells and modules from China far exceeded those of other economies. China's balance of trade of these components was 9.4 billion USD. Imports of polysilicon offset 2.0 billion USD of that balance. China's largest export destination for cells and modules was the United States, which imported 1.8 billion USD.

The largest exporters and importers differ between polysilicon and cells and modules. The United States and Germany were the largest exporters of polysilicon at 1.9 billion USD and 1.3 billion USD, respectively. Both economies also had the highest balance of trade in polysilicon: 1.8 billion USD in the United States and 931 million USD in Germany.

Japan was the largest destination for United States polysilicon exports (842 million USD), followed by China (391 million USD). China was also the largest importer of German polysilicon, purchasing 713 million USD. Japan (186 million USD) was the second largest importer of German polysilicon.

Japan was the largest importer of polysilicon behind China, bringing in 1.4 billion USD from other economies. Most Chinese imports came from South Korea (750 million USD) and Germany (713 million USD). Japan primarily imported polysilicon from the United States (842 million USD) and Germany (186 million USD).

China, the largest exporter of cells and modules, exported 12.3 billion USD in 2014, of which approximately 4.4 billion USD was cells and 7.9 billion USD in modules.[13] Taiwan followed China, although the 4.4 billion USD in cells and modules that it exported was much less than exports from China. About 3.4 billion USD—the majority—of these exports were cells and the remaining 942 million USD were modules.

Japan was the largest importer of cells and modules, purchasing 7.7 billion USD from other economies, primarily China (4.9 billion USD). The United States followed with 4.2 billion USD in imports. Nearly 40% of these, 1.6 billion USD, came from China. China and Malaysia (862 million USD) account for 60% of United States imports. Germany imported 2.4 billion USD in 2014 and was the third largest importer. Taiwan was the largest source of these imports (333 million USD), although these imports are nearly the same as imports from Malaysia and China (280 million USD and 279 million USD, respectively).

Trade flow data are available for polysilicon as well as for cells and modules (tracked together) between economies of interest. The data suggest robust global trade amongst the economies, and generally follow expected flows given the distribution of manufacturing capacity across economies.

c-Si PV Module Market: Demand, Manufacturing Capacity and Production

The global market for PV has to date been characterized by rapid if somewhat inconsistent demand growth across economies, reaching 43 GW of deployments in 2014. Approximately 90% or 38 GW of this demand was for c-Si module technologies. Germany, and to a lesser extent Italy, were major PV demand centers from 2006-2012, after which China, the United States, and Japan became the leading demand markets (Figure 4-6).

While demand growth has been overall very strong for the last ten years (nearly 50% compound annual growth rate (CAGR) 2006–2015), growth slowed to 26% CAGR 2010–2014, and is forecast to moderate to 12% CAGR from 2015 through 2020. Key demand markets through 2020 are expected to include China, the United States, Japan, India, and the United Kingdom (Figure 4-6). Total PV demand across all technologies: c-Si technologies

12. All polysilicon trade is captured in HS code 280461. Solar cell and module trade has different codes in different economies but falls as a subset under 854140. For further information about trade codes used, see CEMAC 2017.

13. Solar cell and module trade is slightly more difficult to estimate due to data availability. Most economies report this with the exception of South Korea and Malaysia, and Japan does not report exports. China, India, Germany, Japan (imports), and the United Kingdom combine cells and modules but do not differentiate between the two. The methodology used to split these apart can be found in the accompanying methodology report, CEMAC 2017.

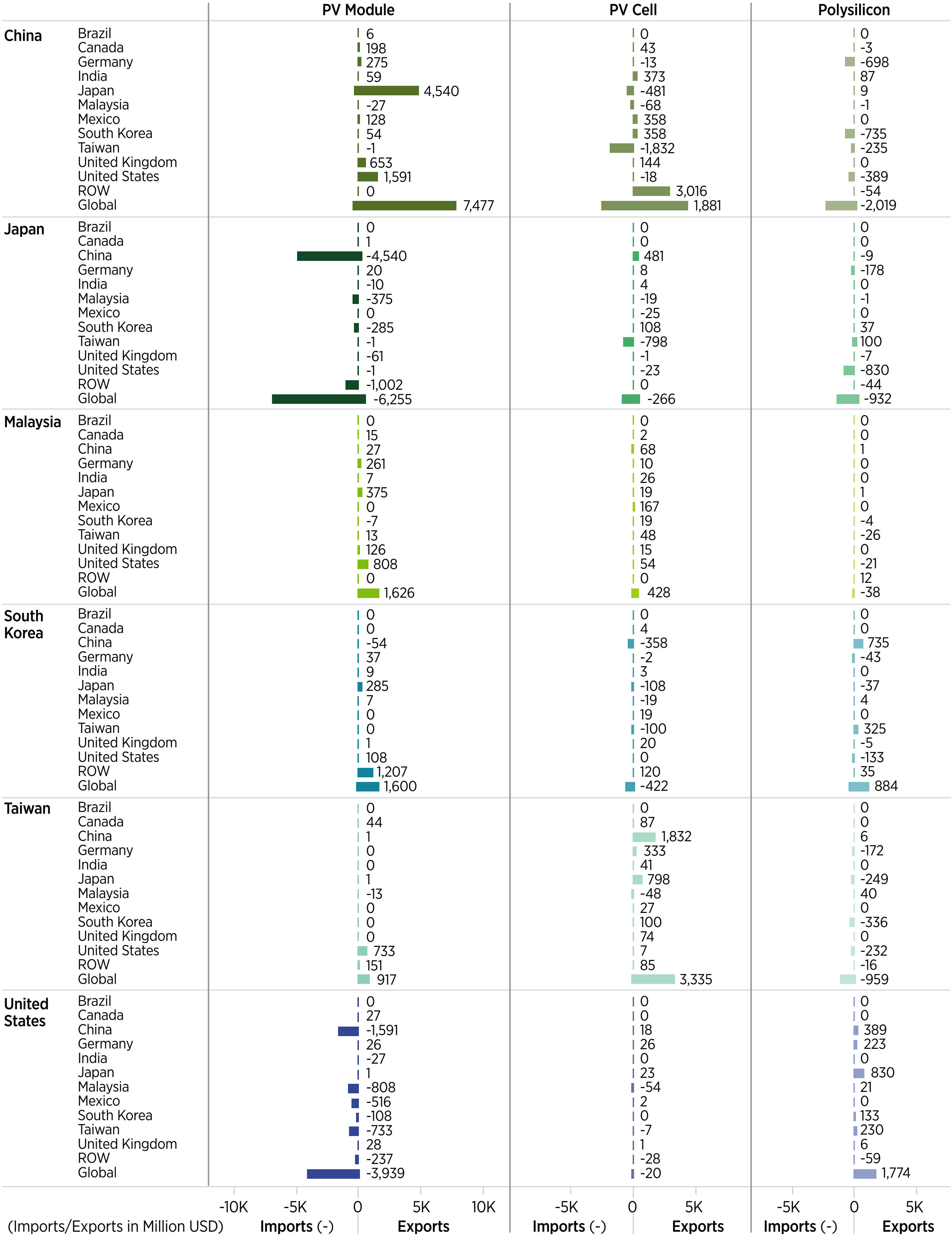


Figure 4-3: C-Si PV modules balance of trade, 2014

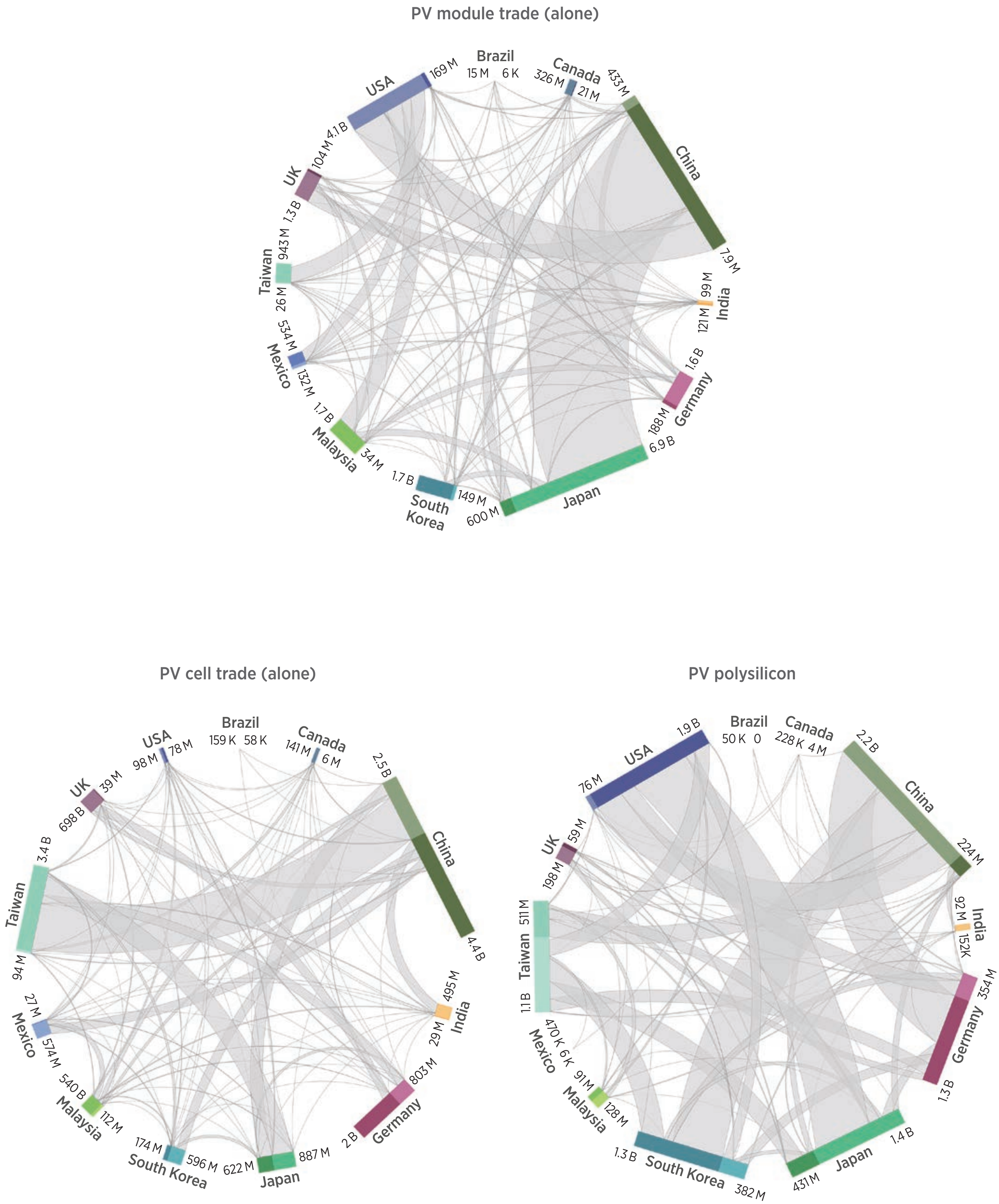


Figure 4-4. Flow of PV modules (for all applications) between key trading partners, 2014 – modules, cells, polysilicon. Darker shades represent exports; lighter shades represent imports.

currently comprise 90% of total demand, and are expected to retain this market share and remain the dominant PV technology type through 2020.

Demand, production and manufacturing capacity along the c-Si PV module supply chain are summarized for the top five economies in Figure 4-5. Global c-Si module, cell and wafer manufacturing is concentrated in China. China is also the largest producer of polysilicon, with the United States, Germany and South Korea each hosting a material share of polysilicon production.

c-Si PV Module Manufacturing Process by Value Chain Link

A simplified representation of the key elements of the c-Si PV module manufacturing (process) supply chain—polysilicon refining, ingot formation and wafering, cell manufacturing, and module assembly—and alignment with the benchmark framework are shown in Figure 4-1. We focus on the PV module as the end product.

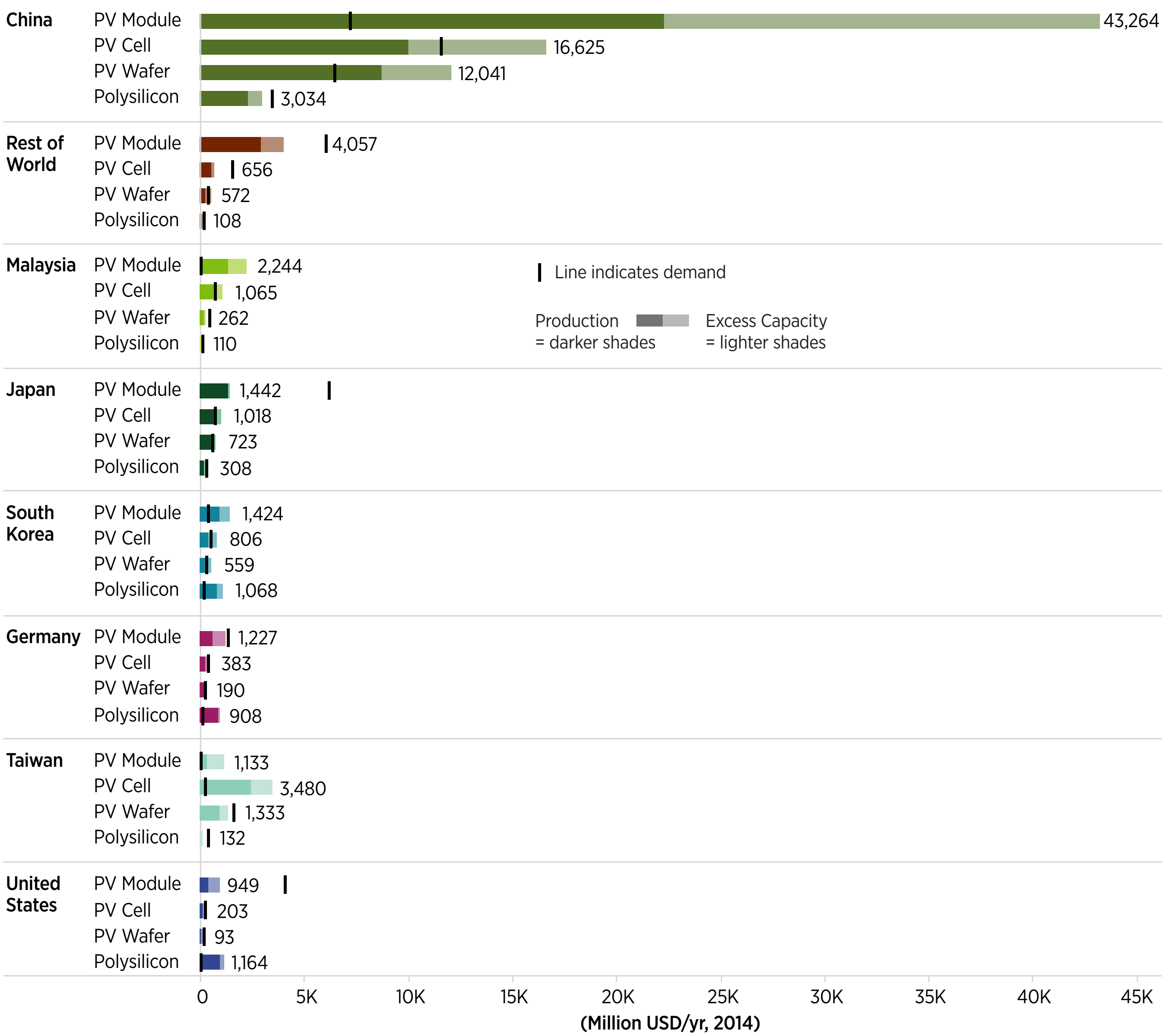


Figure 4-5. C-Si module demand (line), manufacturing capacity (lighter shading, annotated), and production (darker shading), 2014. See methodology report for data quality discussion.

Raw Materials

No raw materials used in c-Si PV manufacture supply chain (e.g. silicon, aluminum, copper) are constrained.

Processed Materials

Polysilicon is the unique and enabling processed material for c-Si PV manufacture; it is imported and exported globally under HTS code 280461. Solar-grade polysilicon production is essentially a chemical processing operation wherein lower purity silicon is refined into 99.999999999% pure (so called "9N" due to the number of 9s to the right of the decimal) silicon, or better. Polysilicon constitutes a major cost component and is critical to overall quality and performance of the PV module.

Subcomponents

Wafers and cells are key enabling intermediate products used in c-Si PV manufacture supply chain. Both are tracked under HS code 854140. Solar-grade polysilicon is transformed into ingots by melting it, adding dopants, and re-crystallizing the melt into ingots via the Czochralski process (for monocrystalline wafers) or via directional solidification (for multicrystalline wafers). The ingots are then cropped and sawn into thin wafers. Ingots and wafers are typically produced in the same facility. Wafers are then texturized, doped to form the semiconducting p-n junction, and metallized, resulting in a finished PV cell. PV wafer and cell quality are both critical to PV performance characteristics such as efficiency and yield.

End Product

In the final PV module manufacturing process, cells are electrically connected, laminated within encapsulants, and sandwiched between a glass layer and a protective backsheet. The entire assembly is then set within an aluminum frame, and a junction box is added, resulting in a complete PV module

Manufacturing Capacity and Production: Origins and Explanations

In the last decade, manufacturing capacity across the supply chain has grown in intermittent bursts with wafer, cell, and module capacity being built well ahead of demand (NREL estimates based on BNEF 2016a, Jin et al. 2016, and ENF 2013,). Manufacturers have generally been willing to build capacity in excess of current demand in anticipation of strong future demand growth. Federal, provincial, and local incentives in China, where a preponderance of global capacity has been built, have also driven growth.

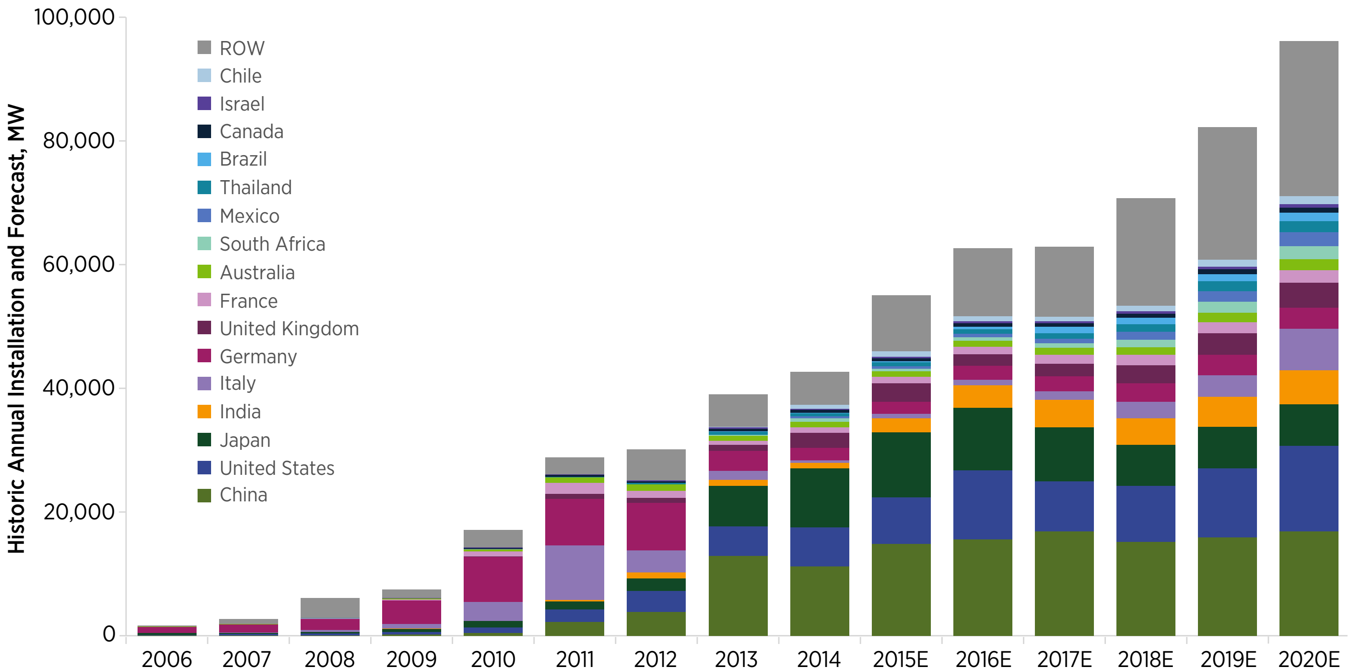


Figure 4-6. Demand growth for PV, 2006–2020E (includes all types of modules). Data from BNEF 2015, James 2015, GTM Research 2015, and Grace and Serota 2015

In 2014, China hosted the majority of wafer, cell, and module manufacturing capacity. Polysilicon production was more equitably distributed, with China hosting 44% of global capacity, while the United States, South Korea, Germany, and all other economies hosting 17%, 17%, 13%, and 7% of capacity, respectively.

Some vertical integration exists across the industry between wafer, cell, and module production, with integrated manufacturers citing lower "in-house" production costs as compared to those achieved when sourcing materials and components from third parties (Chase et al. 2016). The key competitors across the supply chain are summarized in Table 4-1. The first column of the Table 4-1 lists manufacturing locations. Several companies shown own manufacturing assets in economies other than their headquarters locations (e.g. Wacker and SolarWorld are headquartered in Germany, but own manufacturing facilities in the United States; Panasonic is headquartered in Japan, but owns manufacturing facilities in Malaysia and the United States).

PV manufacturing remains highly disaggregated and extremely competitive; several firms compete at each step of the supply chain.

The buildup of manufacturing capacity through 2011 was driven by expectations of continued strong demand growth, and especially in China by local and provincial subsidies and investment supports (Quitzow 2015). The resulting overcapacity drove large price reductions between 2008 and 2012, exacerbated by a slowdown in global demand between 2011 and 2012. However, with robust demand returning and pricing stabilizing, PV manufacturer capital expenditures (related to capacity additions) rebounded again in 2014 and 2015 (data from SEC filings compiled by Feldman et al. 2016).

Table 4-1. Key Competitors Across the c-Si PV Module Value Chain in 2014

Manufacturing Location	PV Module	PV Cell	PV Wafer	Polysilicon
China	Trina, Jinko, Canadian Solar, JA Solar, Yingli	Trina, JA Solar, Yingli, Jinko, Canadian Solar	GCL, LDK, ReneSolar, Yingli, Jinko	GCL, REC
Germany	SolarWorld	SolarWorld	SolarWorld, PV Crystalox Solar	Wacker
United States	SolarWorld, Suniva	SolarWorld, Suniva	Panasonic	Hemlock, REC, Wacker
South Korea	LG, Hyundai	LG, Hyundai, Shinsung Solar Energy	Nexolon, Woongjin Energy	OCI, Hanwha
Malaysia	Hanwha, Panasonic	SunPower	AUO, Comtec	
Philippines	SunPower[a]	SunPower		
Taiwan	Neo Solar	Motech, Gintech, Neo Solar	Gigastorage, Green Energy Technology, Sino-American Silicon Products	

a. SunPower announced in August 2016 that they will close their Philippines module assembly capacity and relocate a portion of it to Mexico (http://www.pv-tech.org/news/sunpower-streamlining-project-development-focus-and-closing-module-assembly)

5 | Manufacturing LDV Lithium-ion Battery Cells

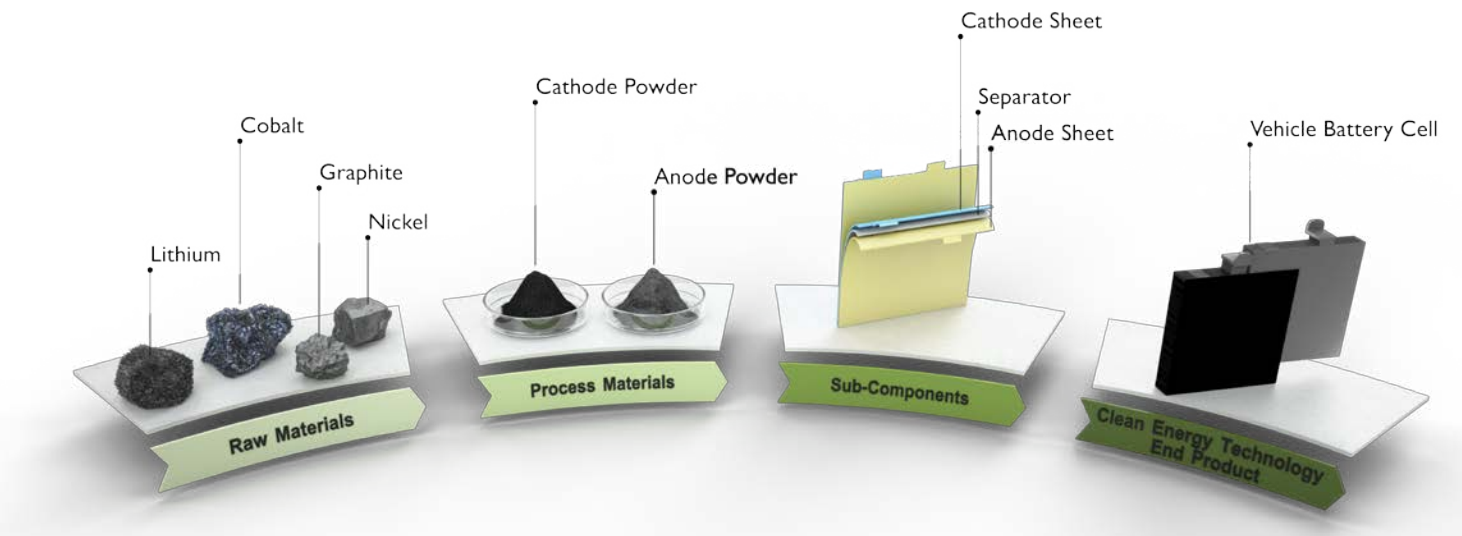


Figure 5-1. How Li-ion cell manufacturing aligns with CEMAC benchmark framework. Illustration by Josh Bauer, NREL

The global market for LDV Li-ion battery cells has grown rapidly as new electric vehicles have come to market. We focus on LDV Li-ion batteries used for light-duty vehicles and particularly on the critical energy storage component within Li-ion batteries: the cell. Cells constitute a large portion of the cost structure for complete battery packs, and cell cost and performance drive overall pack cost and performance. Figure 5-1 shows key elements in the supply chain for LDV Li-ion battery cells.

Cells are frequently semi-customized and thus somewhat specific to the end application (e.g. power- or energy-biased applications). Automotive cells in particular are non-standardized and specific to the vehicles in which they will be installed.

Packs are specific to their particular applications, and are typically designed by, or in close collaboration with the end application manufacturer. This is especially true in automotive applications, where many car manufacturers design and assemble their own packs. Automotive batteries must meet strict performance, life cycle, thermal management, weight, and physical packaging and protection requirements given the duty cycle, operating environments, and life expectancy of automobiles.

Manufacture of LDV Li-ion Cells

- Global annual demand for LDV Li-ion cells (for use in light duty vehicles) reached 9.6 GWh in 2014 (NREL estimate based on Alexander and Gartner 2014, BNEF 2016a, BNEF 2016c, BNEF 2016d, Inagaki 2016, Pillot 2015). Demand is expected to grow at a 31% CAGR between 2013 and 2023 (Alexander and Gartner 2014).
- Opportunities for innovation include advances in cell chemistries, formats, and cell manufacturing processes.
- Automotive cell production costs are not yet at a point where large-scale adoption in vehicle applications is likely. In 2014, electrified vehicles (including pure electric, plug-in hybrid, and hybrid drive vehicle) constituted only 2.8% of global light duty vehicle markets (NREL estimate based on BNEF 2016c, Technavio Insights 2015, Shepard and Gartner 2014). Cost reductions and performance improvements are essential for growth in the electrified vehicle market and overall vehicle market penetration.

Key Findings

- In 2014, Japan, South Korea, and China were home to the majority of manufacturing capacity for Li-ion cells and related intermediate products. The capacity in these economies was originally developed to serve consumer electronics markets.
- With respect to automotive-specific cell manufacturing capacity, the United States was also a major manufacturing nation in 2014, hosting 20% of global capacity.

- Global average capacity utilization for LDV Li-ion cell manufacturing was a relatively low 41% in 2014. Japanese facilities were estimated to have the highest utilization (67%), and Chinese facilities the lowest (17%).
- The United States was by far the largest demand market for LDV Li-ion cells in 2014, comprising nearly 60% of total global demand. However, demand has shifted since 2014 and China is now the leading global demand market.
- Japan led both production of Li-ion battery components and value added, retaining 1.3 billion USD in direct and indirect value added from 1.7 billion USD in production. The United States had the second-highest level of value added (0.6 billion USD), although it was only the fourth-largest producer (0.7 billion USD).
- Japan, China, and South Korea were the largest net exporters of rechargeable Li-ion batteries, both for automobiles and general applications. Reflecting LDV Li-ion battery manufacturing that lags production, the United States and Germany were the primary destinations for automotive rechargeable Li-ion batteries and also the largest net importers of rechargeable Li-ion batteries for any use.

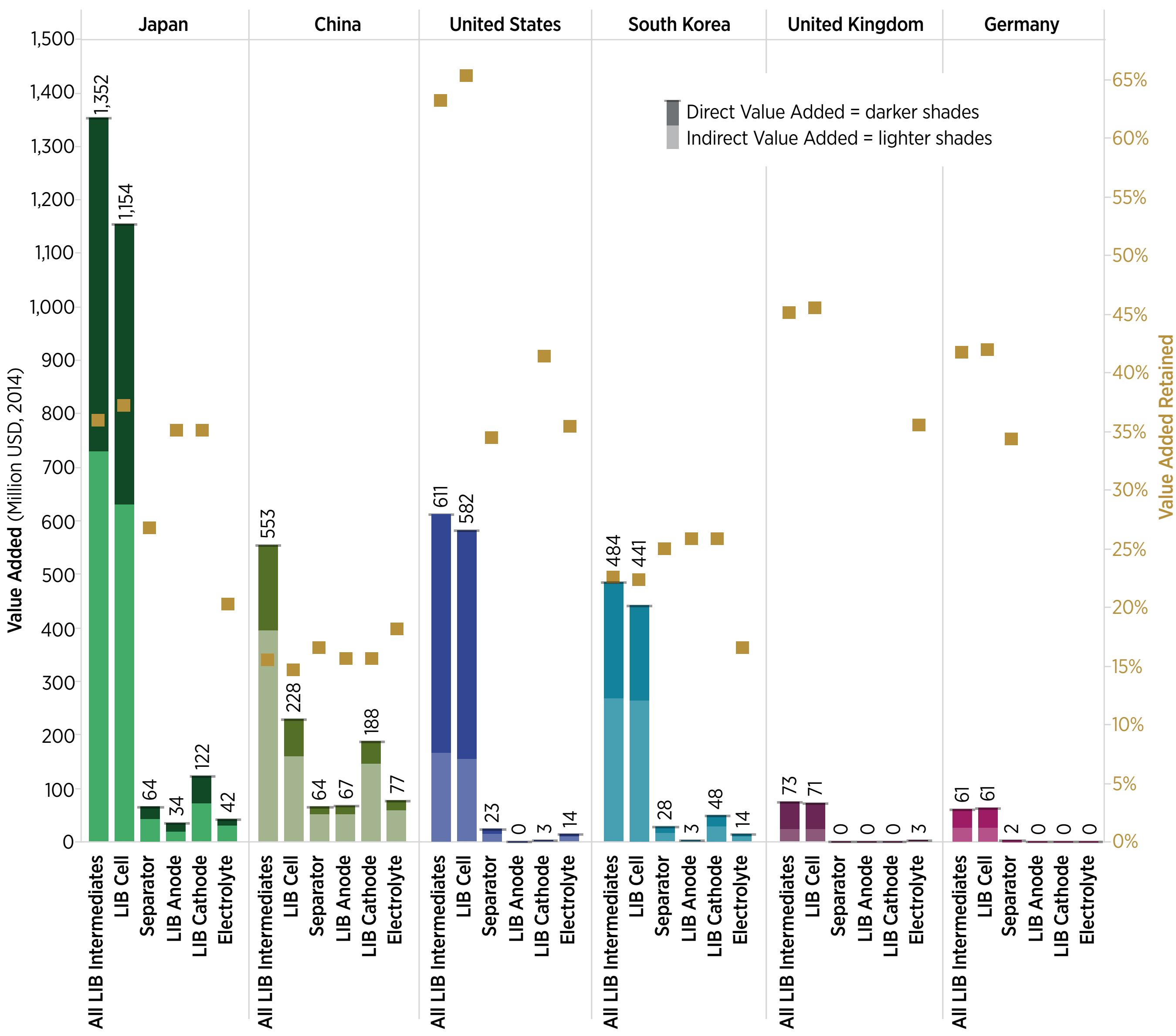


Figure 5-2. Value added—direct (dark shading) and indirect (light shading) for LDV Li-ion batteries, in total and by supply chain link, 2014. Direct value added retained indicated by squares (right axis). See methodology report for data quality discussion.

Value Added

In 2014 total direct and indirect value added for Li-ion vehicle batteries across the 12 economies was 3.1 billion USD. Direct and indirect value added contributed similar portions of this total: 1.5 billion USD direct and 1.6 billion USD indirect (Figure 5-2). Among the top three producers—China, Japan, and South Korea—direct was 1.0 billion USD and indirect was 1.4 billion USD. U.S. manufacturing, in contrast, produced more direct value added (0.4 billion USD) than indirect (0.2 billion). Higher indirect levels could result from more highly developed supply chains that reduce imports. Alternatively, economies with higher indirect value added may earn higher value added per dollar of revenue economy-wide.

More than 40% of the 3.1 billion USD total (1.3 billion USD) was in Japan, the leading producer. The United States followed Japan with 0.6 billion USD in total value added, but is only the fourth-largest producer of battery cells and subcomponents. The United States retains relatively high levels of value added from each unit of production revenue, especially in cells, which comprise more than 90% of what is manufactured in the United States. U.S. producers also support high levels of direct value added per unit of revenue relative to other economies in this report.

Figure 5-2 also shows value added retained. The highest ratio is the 65% in battery cell manufacturing in the United States. Battery cell manufacturing generally produces higher value added as a portion of revenue than other subcomponents (See Appendix). This helps explain why the United States generates more value added than other economies with higher production. China and South Korea both have more balanced production between cells and cathodes than the United States, but value added percentages for both are significantly lower than the United States.

Similar trends emerge when including indirect impacts, or the supply chains for clean energy manufacturing companies (See Appendix). Across all economies and components, U.S. cell production yields the highest percentage of value added: 89%. China and South Korea retain higher percentages of value added in cell subcomponents.

Among subcomponents, the highest level of value added, 2.5 billion USD, came from cell production.[14] This is much higher than the 375 million USD from cathodes, 103 million USD for anodes, 181 million USD for separators, and 151 million USD for electrolytes. Japan retained highest value added for cells (1.2 billion USD), while China achieved highest value added in cathodes (188 million USD), anodes (65 million USD), separators (64 million USD), and electrolytes (77 million USD).

Balance of Trade and Trade Flows

In 2014 the 12 economies had a 172 million USD balance of trade in cells and a 133 million USD balance of trade among all subcomponents for automotive use.[15] Trade balances were negative for automotive cathodes (-32 million USD), anodes (-2 million USD) and separators (-5 million USD). Exports equaled imports of electrolytes, so the trade balance between the 12 economies and the rest of the world was zero. The top three producers of LDV Li-ion batteries—Japan, China, and South Korea—also had the most significant balances of trade: 797 million USD, 626 million USD, and 688 million USD, respectively. The United States was the fourth-largest producer yet it was a net importer with a -1.6 billion USD balance of trade.

Table 5-1. Li-ion Batteries Balance of Trade for Automotive and All Applications, 2014

Economy	**Li-ion battery cells and subcomponents:** Automobiles (all subcomponents) (Billion USD 2014)	**Rechargeable Li-ion batteries:** All applications (Billion USD 2014)
China	0.6	0.8
Germany	-0.3	-0.5
Japan	0.8	1.5
South Korea	0.7	1.8
United Kingdom	-0.1	-0.1
United States	-1.6	-0.9

14. Total value added is adjusted to avoid double counting. Therefore, the total may be less than the sum of all components. We did not make the same adjustments for subcomponents.

15. The HS trade code used for rechargeable Li-ion trade is 850760.

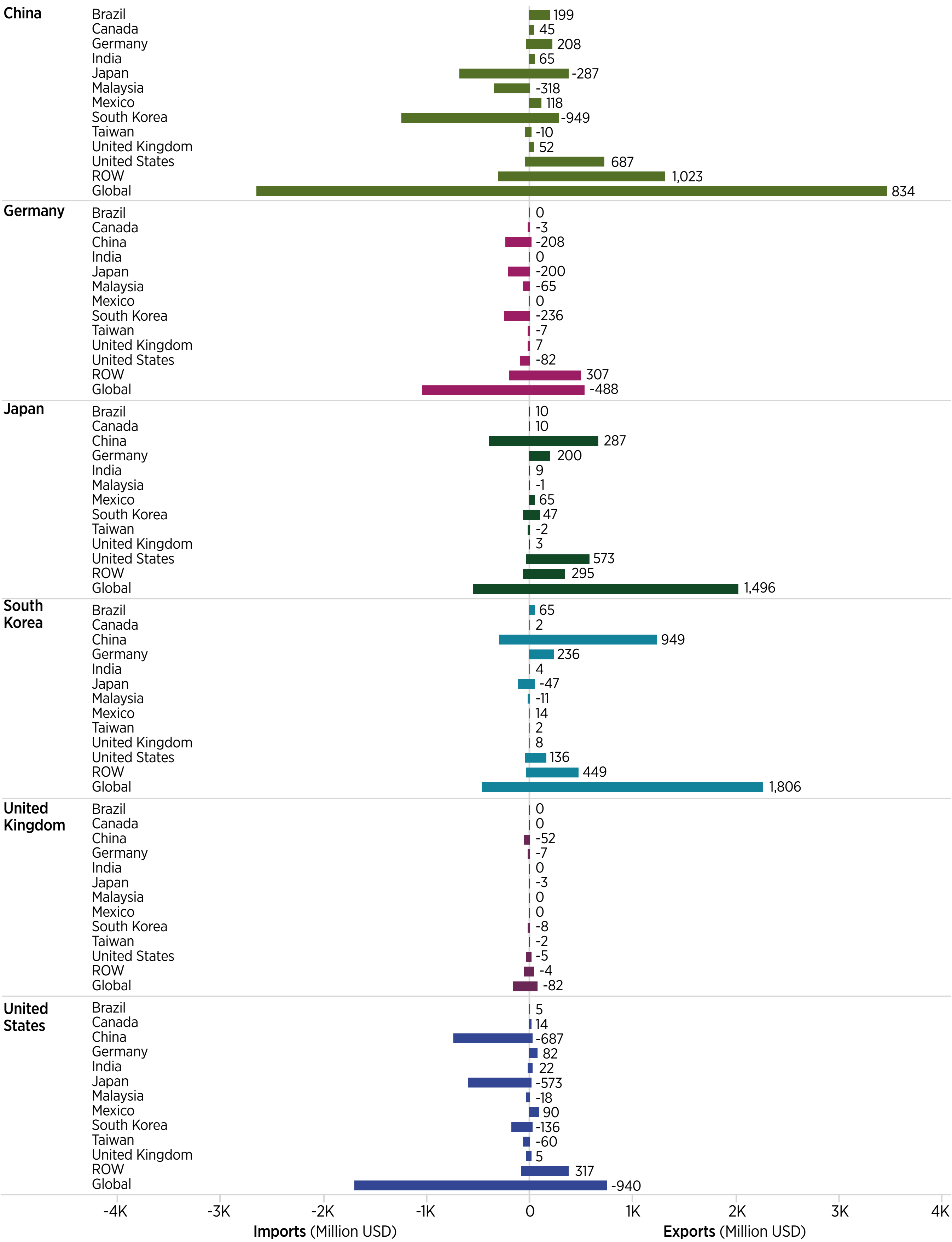


Figure 5-3. Li-ion battery cell balance of trade (for all applications), 2014

This trend is true of the larger rechargeable Li-ion batteries market. In 2014 the 12 economies covered in this report were net exporters of all rechargeable Li-ion batteries, maintaining a 2.5 billion USD balance of trade. This was from 9.9 billion USD in exports and 7.4 billion USD in imports. Table 5-1 shows both vehicle-specific and general rechargeable Li-ion battery balances of trade.

In the United States, the balance of trade for automobile Li-ion batteries and their subcomponents is more negative than the balance for rechargeable Li-ion batteries as a whole. This is because trade in rechargeable batteries for all applications only includes cells, whereas all subcomponents are included in the automobile-specific number. The United States balance for cells in general was -1.4 billion USD. This was a significant portion of the 1.7 billion USD that the United States imported in 2014. While the numbers may indicate that the physical volume or capacity in kWh of Li-ion batteries for vehicles was the overwhelming majority of imports, this may not be the case because the dollar value of automotive batteries is higher than the value for consumer electronics. Furthermore, Li-ion battery imports for consumer electronics are categorized as the electronic device rather than a battery.

China, one of the largest producers of vehicle Li-ion components, was the largest exporter and had the largest balance of trade for rechargeable Li-ion batteries in general. In 2014 it exported 3.5 billion USD while importing 2.6 billion USD. The largest destinations for exports from China included the United States (0.7 billion USD) and Japan (0.4 billion USD). China imported primarily from South Korea (1.2 billion USD) and Japan (0.7 billion USD).

Another one of the top three producers of Li-ion components, South Korea, was the second-largest exporter of rechargeable Li-ion batteries in general, with 2.3 billion USD in exports. Korea exported 1.2 billion USD to China, its most significant trading partner. Its second-largest destination was Germany (0.2 billion USD).

The United States was the largest net importer of rechargeable Li-ion batteries, importing 1.7 billion USD. The largest share of United States imports (0.7 billion USD) came from China followed by Japan (0.6 billion USD) and South Korea (0.2 billion USD). All three of these economies produce vehicle cells and all three have positive balances of trade in Li-ion batteries for use in vehicles as well as rechargeable Li-ion batteries in general. U.S. exports to the 12 economies in this report were small; exports did not exceed 100 million USD.

Germany was the second-largest net importer of rechargeable Li-ion batteries with a -0.5 billion USD balance of trade. As with the United States, major suppliers to the German market were Korea, China, and Japan. Also like the United States, German exports were small; exports to any one of the 12 economies covered in this report were less than 20 million USD.

- As indicated by Figure 5-4, Southeast Asian Li-ion cell production capacity was built to serve domestic consumption as well as export markets. China, Korea, and Japan are net exporters of cells. The United States, Germany, and Brazil are the top net importers of cells.
- The data comparing auto-specific Li-ion cell demand and production also suggest that these overall trade flow patterns, with the exception of Brazil, would also hold true for auto-specific cell trade. Japan, South Korea, and China maintain positive balances of trade while Germany and the United States have negative balances (See Appendix).

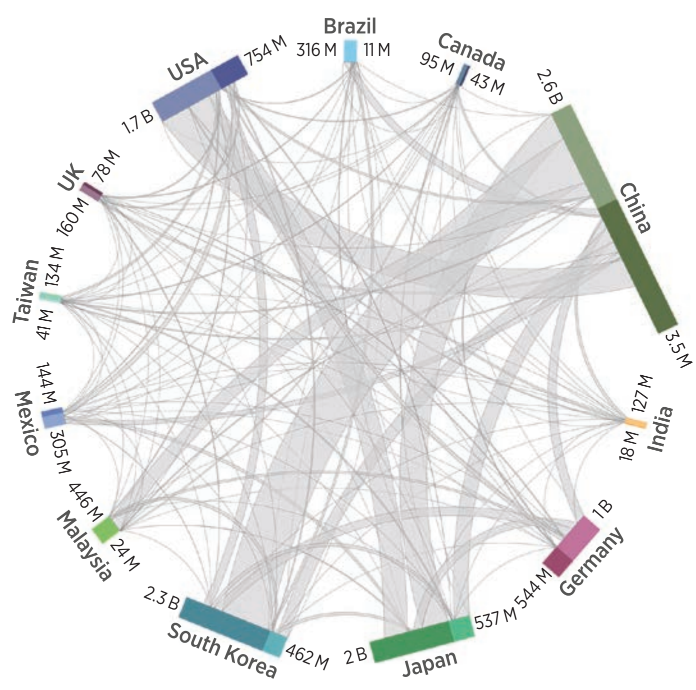


Figure 5-4. Flow of Li-ion cells (for all applications) between key trading partners, 2014. Darker shades represent exports; lighter shades represent imports.

LDV Li-ion Cell Market: Demand, Manufacturing Capacity, and Production

The global market for automotive cells has grown rapidly in recent years as new plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) have come to market.[16] Volumetric demand for batteries (in terms of MWh demanded annually) grew at 144% CAGR between 2011 and 2013, and at 46% CAGR between 2013 and 2015.

Figure 5-5 shows the demand, manufacturing capacity and production for the LDV Li-ion battery cell supply chain in 2014.

In the benchmark year of 2014, the United States constituted the largest LDV Li-ion cell demand center globally with 62% of demand, followed by Japan (14%) and Germany (7%). Strong U.S. demand is a reflection of the significant electric vehicle manufacturing based in the United States: cell demand is directly driven by battery pack production, which is in turn typically co-located with electric vehicle production facilities. Korea and Japan are leading LDV Li-ion cell exporters.

Global LDV Li-ion cell manufacturing utilization was estimated to be 41% in 2014. Amongst the major producer economies, Japan has the highest utilization (67%),

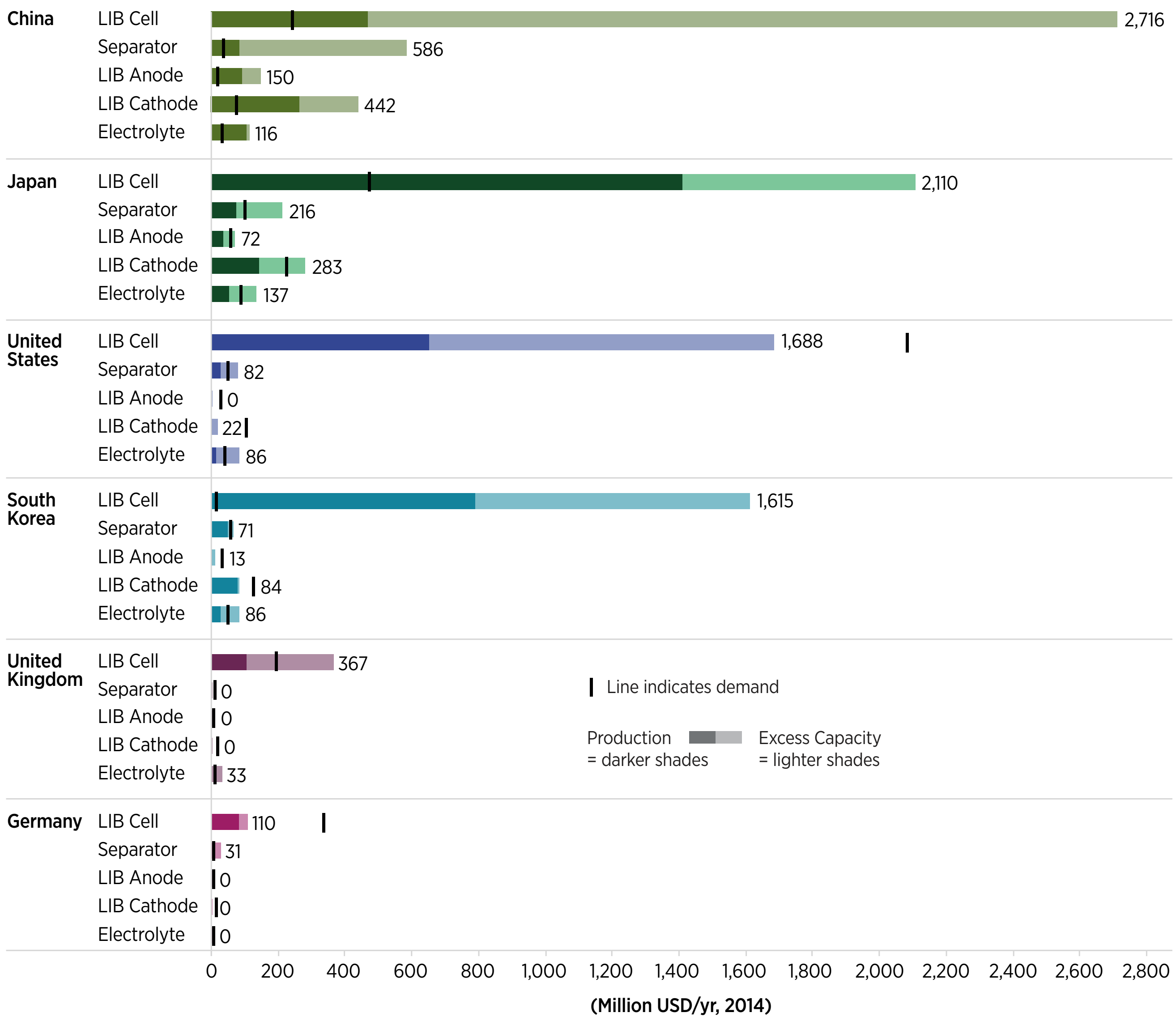


Figure 5-5. LDV Li-ion cell demand (line), manufacturing capacity (lighter shading, annotated), and production (darker shading), 2014. See methodology report for data quality discussion.

16. Hybrid-electric vehicles (HEVs) have contributed to a much smaller portion of Li-ion cell demand, as most HEV did not use Li-ion batteries in 2014.

followed by Korea (49%), the United States (39%), and China (17%). Such relatively low utilization rates partially contributed to sharp cell price reductions between 2014 and 2015.

In 2014, Li-ion cell manufacturing capacity (serving all end market applications) was primarily located in China, Japan, and Korea. Together, these economies constituted 72% of global Li-ion cell production capacity. These economies are home to established clusters of Li-ion cell and related intermediate product manufacturing facilities.

In 2014, the United States was an established LDV Li-ion cell manufacturer, comprising nearly 20% of global LDV Li-ion cell capacity. The United States was also the largest single economy demand market for LDV Li-ion cells in 2014.

Though China hosted the most LDV Li-ion cell capacity of any economy, it ranked fourth in automotive cell production behind Japan, Korea, and the United States.

LDV Li-ion Cell Manufacturing Process by Valve Chain Link

As shown in Figure 5-1, key supply chain elements in the production of Li-ion cells include: specialty materials used to produce the cathodes and anodes; separator materials; and electrolytes.

Raw Materials

Comparing the known reserves of certain materials to their total global consumption rate can highlight materials where supply constraints may arise. Estimates of reserves and consumption suggest that no raw materials used in the Li-ion manufacturing supply chain (e.g. lithium, nickel, cobalt, manganese) are constrained (USGS 2016a).

Processed Materials

Electrode powders (both cathode and anode powders) are unique and enabling processed materials needed for the manufacture of Li-ion cells and batteries. While chemistries can vary, electric vehicle applications typically utilize lithium nickel manganese cobalt (NMC) cathodes and graphite anodes. The common electrolytic solution used is based on lithium hexafluorophosphate ($LiPF_6$) salt dissolved in an organic solvent solution such as ethylene carbonate. These processed materials are all crucial to cell (and thus pack) performance and quality, and together constitute more than 40% of the total cost structure of a Li-ion cell.

Cathodes and anodes are typically produced as part of the cell manufacturing process. Cathodes and anodes are produced from powders (processed materials), which are mixed with solvents and binders, deposited onto a current-collecting foil, dried, and subsequently pressed and cut to specific dimensions. The cathodes and anodes thus take the form of sheets, and together with separators (a subcomponent, also in sheet form) are either wound into a roll or arranged into a stack of alternating cathode–separator–anode layers. Electrolytes are formed by mixing salts ($LiPF_6$) with solvents to form an electrolytic solution.

Subcomponents

Separators are also enabling technologies that serve the crucial function of preventing contact between the cathode and anode, and thus prevent short-circuiting of the cell. Separators are typically made of polypropylene (PP) or polyethylene (PE). As noted above, separators are placed between the electrodes, and along with the electrodes are formed into rolls or stacks.

End Product

The end products are cells. Once a roll or stack is formed, the electrodes are electrically connected, the roll or stack is inserted into a container, and connections, terminals, safety devices, and other items are then added. The container is then filled with electrolyte and fully sealed. Finished cell assemblies are then put through the formation process, a controlled charge and discharge cycle designed to activate the materials. Cells are subsequently assembled into packs, which are ultimately then incorporated into electric vehicles.

Manufacturing Capacity and Production: Origins and Explanations

Li-ion batteries were developed in the 1990s to power consumer electronics. More recently, electric vehicle (xEV) makers began to produce “large format” cells appropriate for automotive use.

In 2014, Li-ion cell manufacturing capacity (serving all end market applications) was primarily located in China, Japan, and South Korea. Together, these economies

Table 5-2. Li-ion Cell Manufacturing Facilities, 2014

Manufacturing Location	Cell	Cathode	Anode	Separator	Electrolyte
China	Wanxiang, BYD, BAK	ShanShan, Reshine, Tianjin B&M	A123, BAK, ATK, Lishen, BYD	Jinhui, Fengfan	Jinhui, ShanShan, CapChem
Japan	AESC, Panasonic, Primearth	Nichia, Sumitomo, JGC	Toshiba, Panasonic	TDK, Ube Industries	Ube Industries, Mitsui, Tomiyama, Mitsubishi Chemical
South Korea	Samsung SDI, LG Chem	Umicore, L&F	LGC, Samsung SDI	Tonen	Soulbrain, Panax-Etec
United States	Panasonic, LG Chem, Tesla			Celgard	

constituted 87% of global Li-ion production capacity for all end-use applications in 2014. Notably, clusters of key intermediate product manufacturing facilities were also well established in these same economies (see Figure 5-2).

Such clusters may contribute to regional supply chain advantages and cost benefits not available to cell manufactures located outside of such clusters. Some degree of vertical integration exists across Asian processed materials and cell production, which may also contribute to lower input costs for certain manufacturers. The United States, in contrast, hosts a relatively immature supply chain, and most U.S. cell and battery plant operators are relatively new to the industry. Nearly all U.S. Li-ion capacity is targeted at serving the emerging automotive market.

Japan's Li-ion cluster grew from sustained investments in Li-ion technology by consumer electronics companies in the 1990s. The Japanese government bolstered private sector investments with R&D funding and low-cost capital to establish manufacturing plants. Japan made these investments despite the long commercialization cycle of Li-ion technologies and the low returns on the Li-ion business because the technology enabled competitive advantages in portable consumer electronics end applications (Brodd and Helou 2013). Korea and China followed Japan's lead in investing in Li-ion cell and pack production for consumer electronics.

Korea's Li-ion battery cell cluster is a result of government and industry efforts, started in the 2000s, to build up this portion of the supply chain within Korea (Bae 2011, Alexander and Gartner 2013). China, too, has fortified its Li-ion cluster development through various government R&D, tax, and investment incentives (Patil 2008), domestic content requirements, and export restraints (Haley 2012, Stewart et al. 2012). While Korean and Chinese cell manufacturers initially relied heavily on Japanese suppliers, their national efforts to build Li-ion clusters have resulted in less dependence on Japanese suppliers, and may contribute to advantageous pricing on key materials for fully scaled, co-located Korean and Chinese cell producers (Bae 2011, Alexander and Gartner 2013).

Historically the United States has not been a leader in Li-ion manufacturing, and in 2014 hosted 7% of global Li-ion capacity for all applications. However, Tesla's 2014 announced plan to build a 35 GWh Li-ion manufacturing facility in Nevada would significantly increase the U.S. share. As of August 2016, the facility is approximately 14% completed (BNEF 2016b), and has begun production of packs using imported cells.

6 | Manufacturing Wind Turbine Components

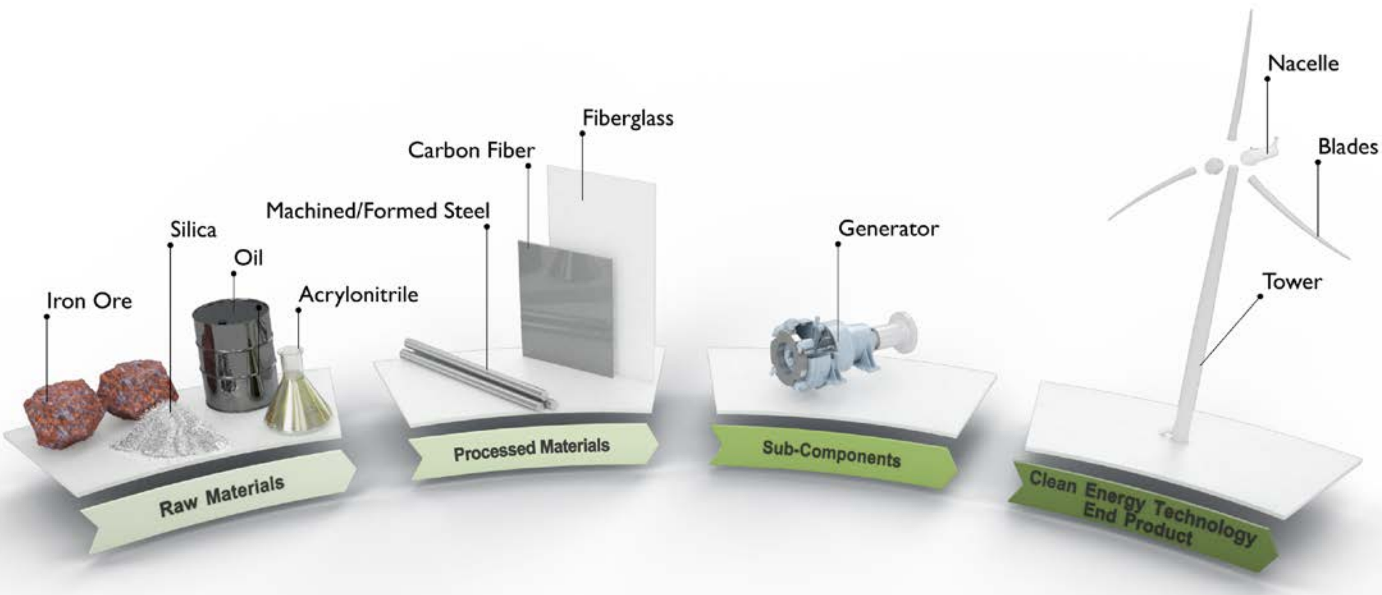


Figure 6-1. How wind turbine manufacturing aligns with CEMAC benchmark framework. Illustration by Josh Bauer, NREL

Wind energy has more installed capacity than any other non-hydro renewable energy source globally. In 2014, an estimated 51 GW of new wind capacity was installed around the world, representing an increase of 44% from 2013 installations (GWEC 2016). Total cumulative installed wind capacity as of year-end 2014 was nearly 370 GW (GWEC 2016). Wind capacity additions are expected to continue apace with recent trends (GWEC 2016).

Figure 6-1 represents a simplified version of the key elements of the supply chain for the wind turbine manufacturing process, aligned to the benchmark framework. We focus our analysis on steel, generators, blades, nacelles, and towers.

Manufacture of Wind Turbine Components

- REN21 (2015) estimates total global investment in wind power in 2014 at 99.5 billion USD. Focusing on new capacity additions alone suggests a potential value of 60–90 billion USD, depending on global installations (35–50 GW/year) and expected costs (1,600–1,800 USD/kW).
- The wind turbine constitutes approximately 75% of initial installed capital costs (Wiser and Bolinger 2015) and approximately 55% of life-cycle costs (Moné et al. 2015). Accordingly, the bulk of the economic opportunity from wind energy is accrued by the persons and economies that produce the hardware and equipment for wind power facilities.
- Many wind turbine components are quite large, and cost for transporting these large components is not trivial. Transportation costs shape global trade in wind energy components. As many innovations target continued scaling and growth in wind turbine components, innovative solutions to transport and logistics challenges will become increasingly important.
- Large portions of the wind energy supply chain connect well to core manufacturing industries including steel producers and fabricators, industrial generator and gear producers, and carbon fiber and composite manufactures. Such complementarities can create both opportunities and challenges for suppliers and potential suppliers of wind turbine components.
- Potential development of offshore wind and more moderate wind-speed resource areas creates opportunities for innovation including taller, lighter towers; longer, lighter blades; and lower nacelle and rotor weights. In addition, these advances expand the accessible wind resource. Innovation needs and a growing resource have the potential to open new doors to non-traditional players and entrepreneurs around the globe.

Key Findings

- From the 1970's until the early-2000s, wind turbine components were primarily manufactured in the European Union and transported around the world. Today, the wind industry has manufacturers located in dozens of economies serving both local and regional markets (Wiser and Bolinger 2015, Linnane 2015).
- The modern wind turbine is composed of more than 8,000 individual subcomponents (EWEA 2009). Approximately 90% of the value of these subcomponents is reflected in estimated costs for three main component groups: nacelles, blades, and towers (Moné et al. 2015).
- In 2014, there was an estimated 90 GW of global wind energy manufacturing capacity for wind turbine nacelles (MAKE 2015b), but global demand in 2014 equaled 51 GW. This suggests a general excess of manufacturing capacity relative to current demand, at the global level.
- China has 5 of the 10 largest global wind turbine manufacturers. These manufacturers serve Chinese demand. At the same time, China accounts for large quantities of primary input materials (e.g., steel plate) and sub-components (e.g., castings, generators, and towers) that serve the global wind industry (Linnane 2015, Wiser and Bolinger 2015).
- Raw materials, process materials, and sub-components tend to be produced and shipped globally. In contrast, end product manufacturing and assembly facilities tend to be located in the largest markets due to the transportation and logistics challenges of moving oversized components (e.g., assembled nacelles) to project sites. Access to good roads, rails, and ports are essential for locations to be able to serve a given regional market (James and Goodrich 2013, Fullenkamp and Holody 2014).
- U.S. production of current 2 MW and next generation 3 MW wind turbines is notable with capabilities present for blades, towers, generators, and gearboxes (GLWN 2014). Current U.S. domestic content estimates include 80%–85% for towers, 50%–70% for blades and hubs, and more than 85% for nacelle assembly; however, as much of the nacelle internals are imported, domestic content for wind turbine equipment as a whole was estimated at approximately 40% in 2012 (Wiser and Bolinger 2015).
- A persistent gap in the current U.S. supply chain is the large structural castings used in the nacelle; at present U.S.-based manufacturers tend to import these castings from Asia and South America. As turbines grow and these components become increasingly difficult to ship, absent alternative design innovations, domestic capacity to produce these components may become more critical (GLWN 2014).
- At 32.5 billion USD in 2014, value added from wind component production was the highest among the four clean energy manufacturing products included in this report. The highest levels of value added came from nacelles (18.1 billion USD) and blades (8.7 billion USD).

Value Added

Value added from the production of wind nacelles, blades, towers, steel, and generators was 32.5 billion USD in 2014 (Figure 6-2). Direct value added was 13.7 billion USD and indirect was 18.8 billion, so in aggregate across the economies in this report the wind supply chain added more to GDP than the producers themselves. Among economies in this report with value added greater than 1 billion USD, however, indirect only exceeds direct in Brazil, China, and India. Direct is greater than indirect in the United States and Germany, which also generally have higher value added retained.

China had the highest production levels across wind subcomponents with a total of 19.2 billion USD in revenue. This revenue drove 7.0 billion USD in direct value added and 12.2 billion USD in indirect value added. The highest value added levels in China were in nacelle production (10.6 billion USD), followed by blades (5.5 billion USD), towers (3.4 billion USD), generators (890 million USD), and steel (206 million USD).[17]

This order holds across economies for both production revenue and value added. Nacelles led in total value added with 18.1 billion USD, followed by blades (8.7 billion USD), towers (5.9 billion USD), generators (1.4 billion USD), and steel (292 million USD).

17. Value added by subcomponents does not sum to total value added levels. This is because subcomponent value added levels were estimated independently and total value added levels account for double counting between subcomponents.

In contrast, China's direct value added retained was 26%, short of the 30% average across all economies in this report and wind components. China does exceed the average across components in blade manufacturing (44% compared to a 41% average).

The UK is first among all other economies in direct value added retained from production. However, the UK only produces wind towers, so this is not representative of the entire wind turbine supply chain. The United States retained the highest percentage of value added as a portion of revenue for nacelles (38%), blades (48%), and generators (41%). The UK and Canada led in towers with 46% and Japan is first in steel with 30%.

Wind manufacturers themselves, then, tend to have higher levels of value added per unit of production in the United States, the UK, Canada, and Japan.

Different trends emerge when considering the overall wind supply chain by including indirect impacts. For direct and indirect value added as a portion of revenue, Brazil is highest all economies in this report overall, with an average of 82% in direct and indirect value added retained as a portion of revenue. Brazil also is first with blades (90%), towers (85%), and steel (82%) (See Appendix). Japan retains the most value added in the production of nacelles (85%) and generators (84%). These percentages show the significance of a domestic supply chain for clean energy

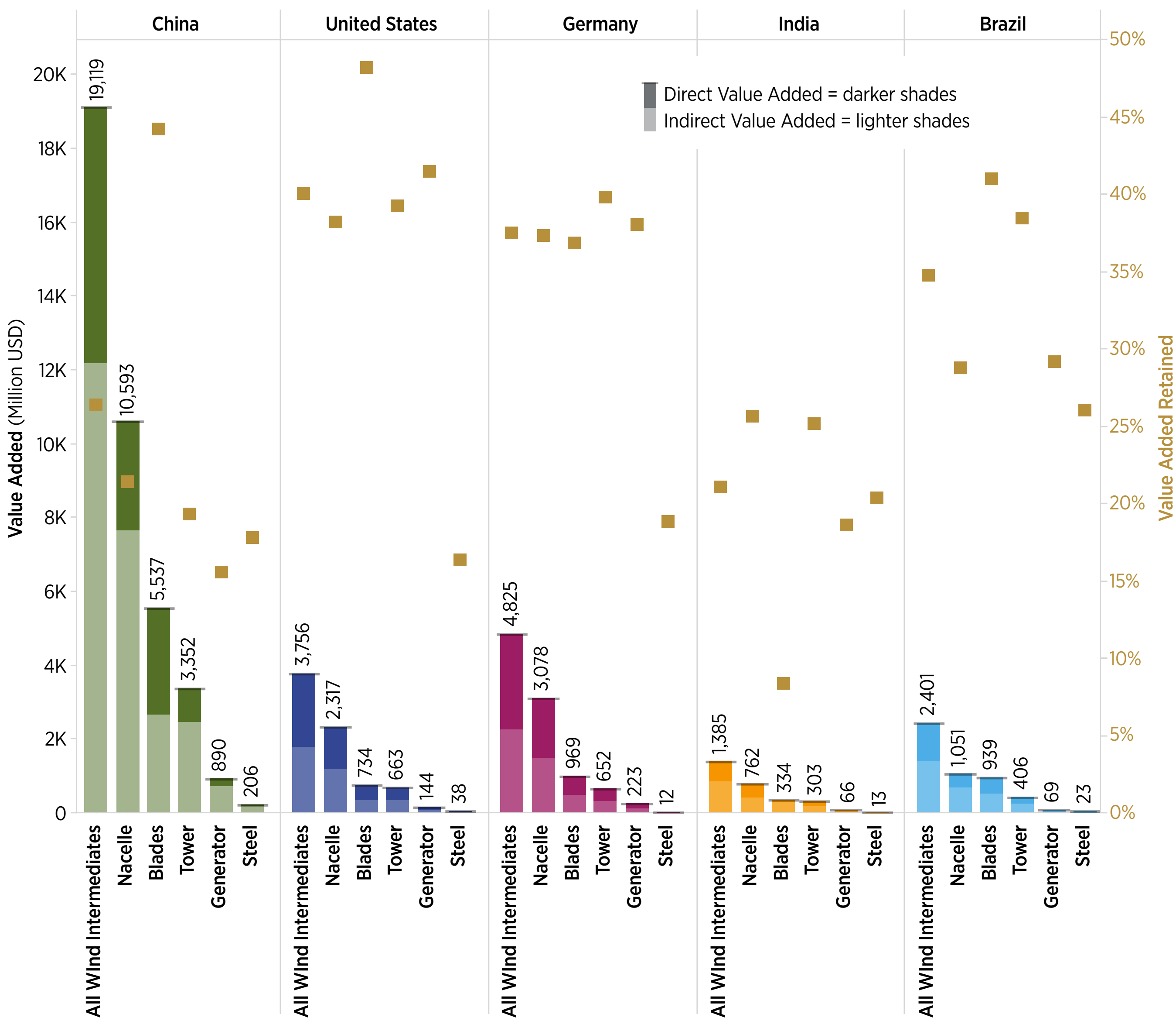


Figure 6-2. Value added in wind turbine manufacturing, by economy and supply chain step, 2014 (left axis). Direct value added shown with dark shading and indirect value added shown with light shading. Direct value added retained indicated by squares (right axis).See methodology report for data quality discussion.

manufacturing products. The producers themselves may support high levels of value added from their production, but their greater supply chains are a part of the overall impact. The development of these supply chains influences the total impact of clean energy manufacturers.

Balance of Trade and Trade Flows

International trade codes only isolate wind generator sets,[18] which are a combination of an assembled nacelle and blades. Trade for wind generator sets is shown in Figures 6-3 and 6-4. Nacelles, blades, or generators that are shipped separately fall under different trade codes and were not tracked in 2014. Because trade codes do not permit direct analysis, we estimated balances of trade by taking the difference between domestic production and domestic demand (see Table 6-1).

In 2014 the economies included in this report exported 3.3 billion USD in generator sets while importing 2.9 billion USD, a positive 324 million USD balance of trade with the rest of the world. As shown in Figure 6-4, Germany led exports (2.2 billion USD) while Canada had the highest imports (628 million USD).

Germany also maintained the most significant balance of trade, with 1.7 billion USD. Canada had the most negative balance of trade (-614 million USD).

Similar trends emerge when estimating trade balances by subtracting domestic demand from domestic production (Table 6-1). Across nacelles, blades, generators, steel, and towers individually (rather than packaged together), Germany had the highest net positive difference (1.1 billion USD). The difference was most negative in the UK (-1.8 billion USD) and Canada (-1.6 billion USD).

Unlike trade of generator sets, domestic demand was 2.0 billion USD greater than what was produced across the 12 economies. Demand exceeded domestic production across all wind turbine components, led by blades (-858 million USD) and nacelles (-757 USD).

Wind Turbine Market: Demand, Manufacturing Capacity and Production

China, the United States, and Germany have been and continue to be the primary global wind power markets. In years past, European economies including Spain, the UK, France, and Italy have also added substantial wind power capacity as has India and Canada. More recently Brazil's role in the global wind power industry has increased while European markets have slowed and turned their attentions offshore. India and Canada continue to add steady growth on the order of 1-3 GW per year (GWEC 2016). Growth in Denmark and the Netherlands, two of the original European wind power pioneers has been limited in recent years, in part due to land-use constraints and a large number of installed and operating wind facilities already present within their high quality resource regions. Like other parts of Europe, Denmark and the Netherlands have also shifted focus offshore.

With the partial exception of Denmark, manufacturing capacity and production has tended to track growth in the primary markets. China, the United States, Germany, Brazil, and India generally lead the production and assembly of wind turbine components (Figure 6-5). Japan, Canada, and South Korea have more modest manufacturing capacity and production levels. Total estimated manufacturing capacity for nacelles, blades, towers, and generators is estimated at approximately 90 GW, 85 GW, 61 GW, and 59 GW respectively (MAKE 2015b). Historically Denmark's prime mover position in wind power as well as the proximity of demand throughout Europe supported significant levels Danish wind power manufacturing but more recently as the industry has globalized and demand in Europe has slowed manufacturing has slowly moved away from Denmark.

Today the manufacturing capacity in China, the United States, and India tends to serve domestic demand. Despite some efforts by Chinese OEMs to expand beyond their domestic market, there are limited shipments of finished wind turbine components even to other economies in Asia (CWEA 2015). U.S. trends are similar; domestic production is largely consumed by U.S. projects. However, the United States has historically exported low volumes of wind turbine components to Canada as well as Central and South America (Wiser and Bolinger 2015). In contrast,

18. Wind generator sets fall under HS code 850231. U.S. trade codes did not isolate blade imports until 2015. Blade import data are not available for 2014.

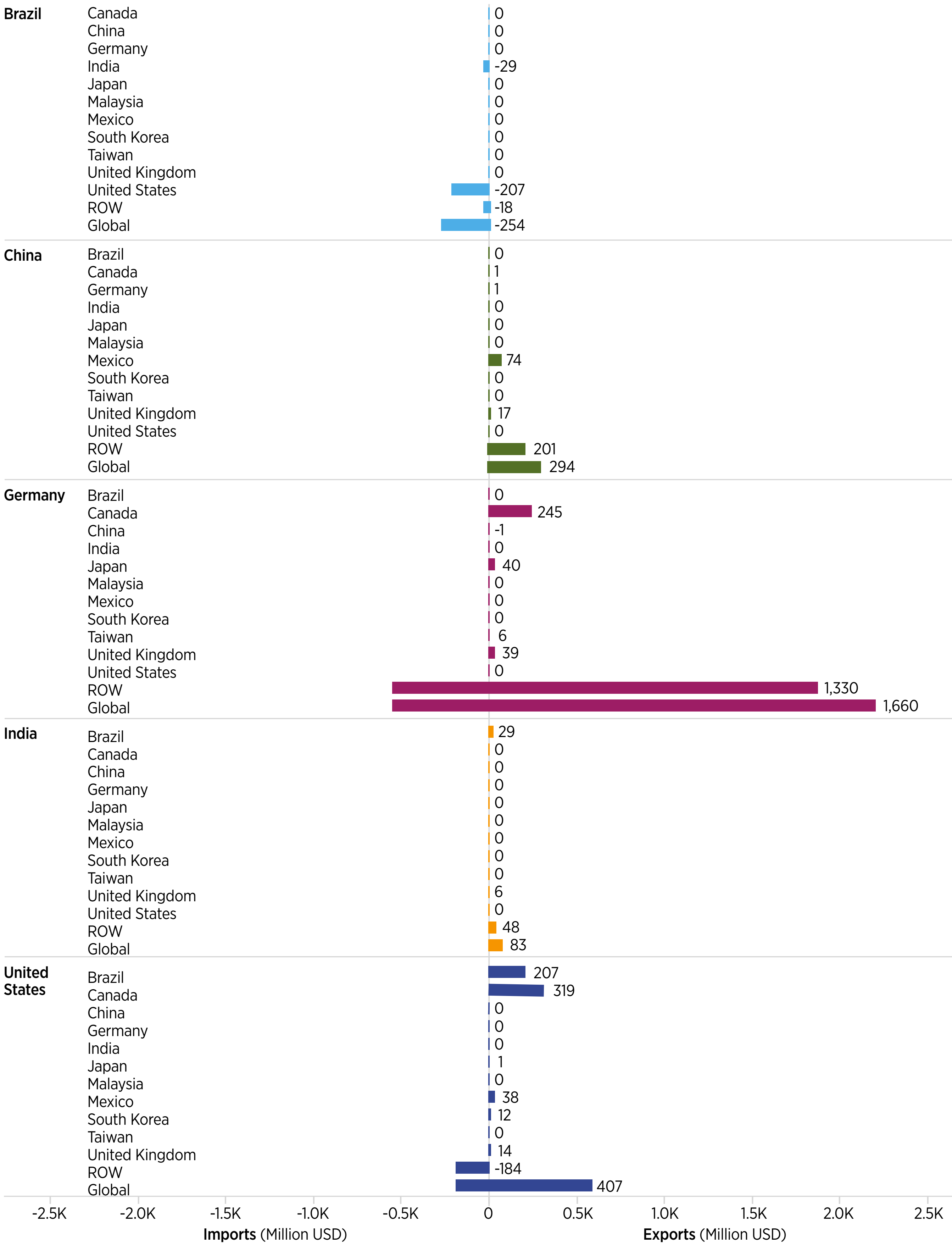


Figure 6-3. Balance of trade for wind turbine generator sets, 2014. See methodology report for data quality discussion.

European manufacturing facilities, particularly in Germany are serving European demand and shipping turbines to Africa and the Middle East along with North and South America (MAKE 2015a). Although the trade flow data described here are not comprehensive, the data generally support broader trends elicited from industry analysis.

Wind Turbine Manufacturing Process by Value Chain Link

A simplified version of the key elements of the wind turbine manufacturing supply chain and alignment with the benchmark framework is shown in Figure 6-1. We focus on the nacelles, blades, and towers as end products.

Raw Materials

The majority of raw materials used to manufacture wind turbine components are commodities that are not constrained (e.g., iron ore, copper, aluminum, carbon). Rare earth metals, neodymium and dysprosium, used for direct drive magnetics in some turbine generator designs, are constrained (China produces 90% of global supply). DOE has listed rare earth metals as critical materials (DOE 2016b), meaning they may have supply challenges due to a lack of supply diversity and volatile pricing. Moreover rare earth metals have been the subject of trade disputes between China and the rest of the world and as such remain an area of potential concern.

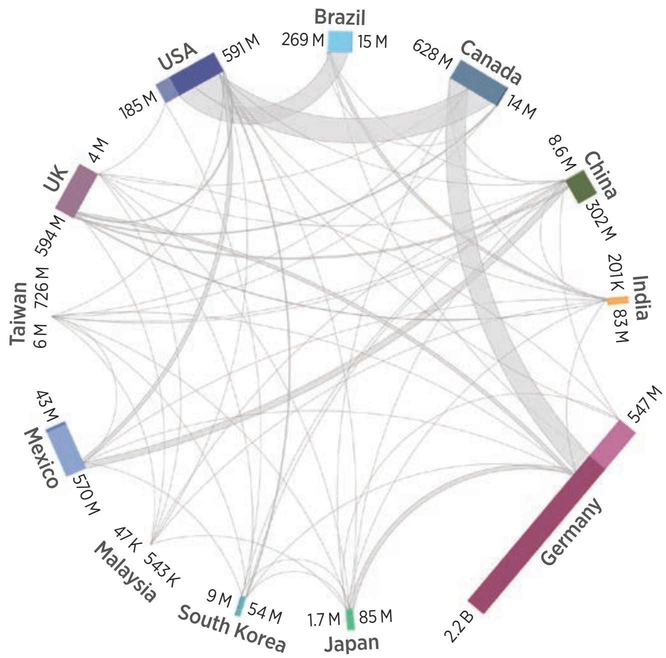


Figure 6-4. Flow of wind turbine generator sets (blades and nacelles)[a] between key trading partners, 2014. Darker shades represent exports; lighter shades represent imports.

a. International trade of towers is not currently tracked.

Table 6-1. Domestic Demand Less Domestic Production for Wind Tower Components (millions USD)

	Nacelles	Blades	Towers	Steel	Generators	Total
Brazil	-155	378	–	–	-47	176
Canada	-1,093	-328	-20	-21	-100	-1,562
China	216	218	156	–	21	611
Germany	1,251	-77	-135	–	28	1,067
India	–	–	85	–	–	85
Japan	199	66	-25	-1	14	254
Malaysia	–	–	–	–	–	–
Mexico	-370	-172	-81	-7	-34	-665
Korea	31	-13	266	-1	3	287
Taiwan	–	–	–	–	–	–
UK	-1,014	-471	-165	-19	-93	-1,763
USA	180	-460	-121	–	-74	-475
Total	-757	-858	-41	-49	-281	-1,985

Source: MAKE (2015b); NREL Analysis

Processed Materials

Wind turbines are steel intensive structures; the towers, nacelle structural components, and the drivetrain make up more than 80% of the weight. However, wind turbine components account for less than 2% of all steel used globally. Large steel casting facilities not do exist in the United States for the wind industry. Most cast parts for the U.S. wind market come from Asia and are not tracked in HTS codes. The large structural castings used in the nacelle come mainly from Asia or South America. Pig iron, which is the basis for wind turbine large structural castings, is processed from iron ore and is some of the most inexpensive steel produced on a USD/kg basis.

Manufacturing of rare earth magnetics occurs mainly in China. About 20% of all turbines installed globally, both land-based and offshore, use rare earth magnets due to the market constraints. China produces almost 90% of all Neodymium magnets, and consumes 75% of the global supply of rare earth magnets. New mines and processing facilities outside of China could increase the use of rare earth magnet generators.

Subcomponents

Wind turbine generators are a sub-component of the nacelle (the housing and associated sub-components that sit atop the wind turbine tower). Generators take the torque created by the rotor and convert it to electricity. Wind turbine towers are typically tubular steel structures used to lift the nacelle and rotor into the air with sufficient ground clearance to allow safe operation and to reduce surface disruptions of the wind resource.

Generators are made primarily from steel (cast, forged, and machined) and coiled copper. Wind turbine generators come in forms including asynchronous, induction singly-fed, double fed, and the newer permanent magnet and direct drive generators. Depending on the configuration, the generator can weigh 2 metric tons and up. The generator is usually manufactured by specialist companies and then sent to the turbine OEM for assembly in the nacelle.

End Product

Wind turbines are the final end-product capable of converting energy in the wind to electricity using torque. They consist of three traded components: blade, tower, nacelle. Wind turbines are sold into a global market, and each main manufacturer (GE, Siemens, Vestas, Gamesa, Suzlon, etc.) has its own supply chain.

Wind turbines are sold into a global market, and each main manufacturer (GE, Siemens, Vestas, Gamesa, Suzlon, etc.) has its own supply chain.

Wind turbine nacelles sit atop the tower and consist of a composite housing to protect the internal components from weather, the structural supports needed to support power generation equipment and the rotor, the full power conversion hardware typically including a low- and high-speed shaft, a gearbox, the generator, and power electronics. The nacelle typically consists of thousands of individual subcomponents. Nacelle manufacturing typically refers to the assembly of the various subcomponents into a functionally complete package. The nacelle is the most expensive component of a wind turbine, accounting for approximately 58% of the cost turbine, due to the complex equipment for the drivetrain, structural, control panels, and yaw assembly.

A "generator set" is a trade code term that refers to a complete nacelle, rotor, and blade package. The trade flow analysis included here is based only on the generator set as defined above due to data limitations for economies other than the United States.

Wind turbine blades are the composite structures that make up the wind turbine rotor. Modern machines have three blades per turbine. Blades are a combination of fiberglass composite, carbon fiber, and epoxy designed to be lightweight to capture as much energy as possible. For most land-based wind turbines, each blade weighs approximately 5–8 metric tons and is 42–56m in length. Transportation from factory to project site is currently a limiting factor due to blade root diameter, cord length, and overall length. Shipping by intercontinental sea-freight does not provide as great a logistical challenge but adds cost and does not eliminate logistics challenges associated with moving blades from port to project site. Manufacturing the blades is relatively inexpensive; blades account for approximately 15% of the turbine value. The remaining 9% of the turbine value is attributed to the hub, which connects the blades to the drivetrain.

Wind turbine towers are generally made of welded steel plate with varying thickness, weigh upward of 160 metric tons, and account for approximately 18% of the total wind turbine value. Towers are the component that is

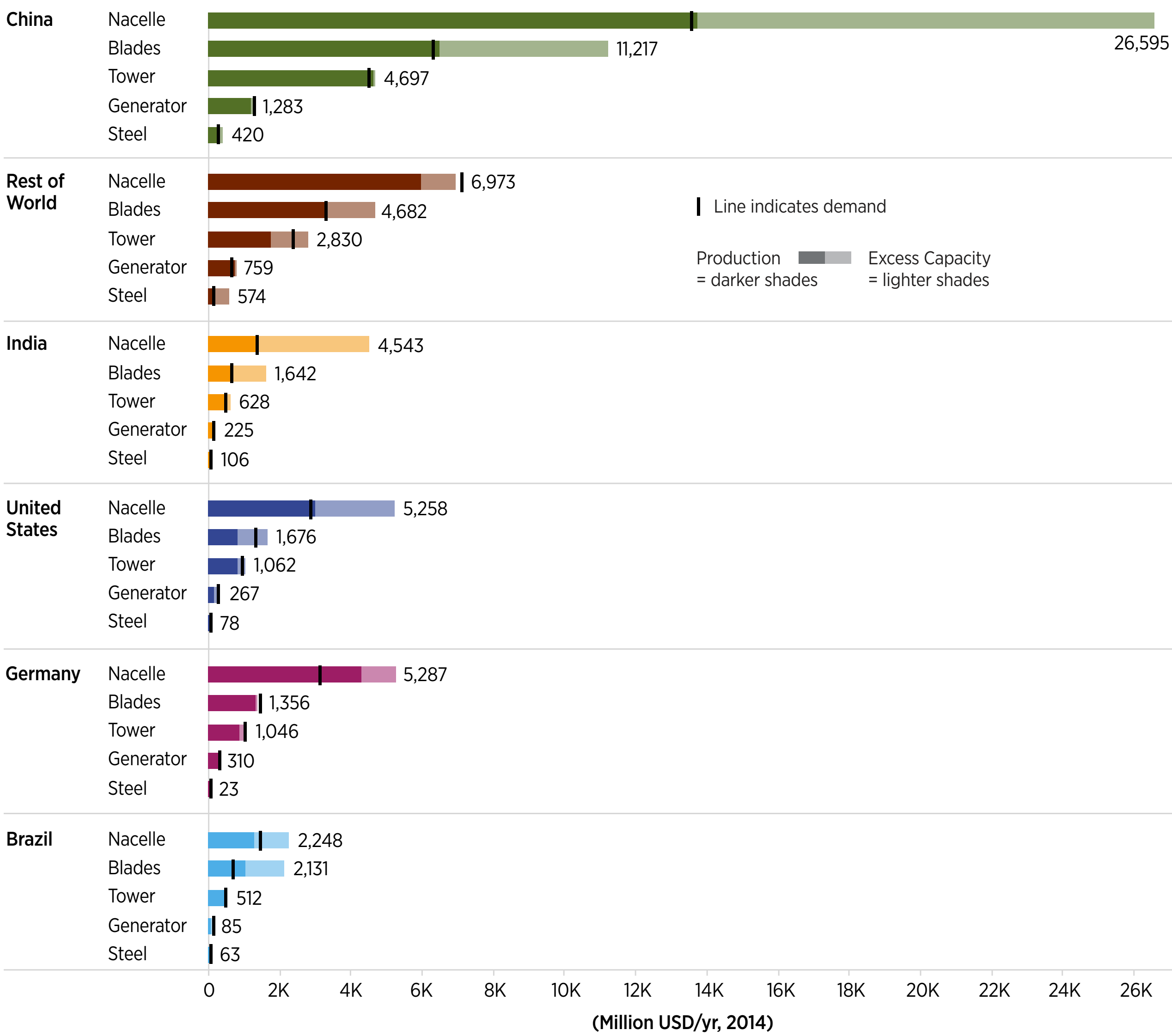


Figure 6-5. Wind turbine demand (line), manufacturing capacity (lighter shading, annotated), and production (darker shading), 2014. See methodology report for data quality discussion.

most often outsourced from the turbine manufacturer. Manufacturing of towers has the biggest global footprint of the three main components. Manufacturing is typically independent of the origin points of mined iron ore and manufactured steel plate.

Blades are a combination of fiberglass composite, carbon fiber, and epoxy designed to be lightweight to capture as much energy as possible. For most land-based wind turbines, each blade weighs approximately 5–8 metric tons and is 42–56m in length. Transportation from factory to project site is currently a limiting factor due to blade root diameter, cord length, and overall length. Shipping by intercontinental sea-freight does not provide as great a logistical challenge but adds cost and does not eliminate logistics challenges associated with moving blades from port to project site. Manufacturing the blades is relatively inexpensive; blades account for approximately 15% of the turbine value. The remaining 9% of the turbine value is attributed to the *hub*, which connects the blades to the drivetrain.

Towers are generally made of welded steel plate with varying thickness, weigh upward of 160 metric tons, and account for approximately 18% of the total wind turbine value. Towers are the component that is most often outsourced from the turbine manufacturer. Manufacturing of towers has the biggest global footprint of the three main components. Manufacturing is typically independent of the origin points of mined iron ore and manufactured steel plate.

Assembly on Site

Although not included as part of the manufacturing supply chain, wind turbines are assembled at the project location. The various end products and subcomponents in some cases are shipped from individual factories to the site. On-site assembly is comprised of turbine assembly or installation of industrial machinery and equipment, electrical installation, other construction installation, and technical testing and analysis. On-site assembly is critical due to the logistics challenges associated with transport of large wind turbine components. As turbines continue to scale with technology R&D and innovation, maintaining high levels of efficiency in time and cost during the on-site assembly process will be essential to enabling continued wind power cost reductions and improvements. Innovative manufacturers also continue to explore opportunities for increased on-site fabrication and production of wind turbine end-products and subcomponents in order to enable larger more productive wind turbines to be installed while minimizing transport costs and logistics hurdles. If these innovations are successful wind turbine equipment fabrication and production may be increasingly moved on-site.

Manufacturing Capacity and Production: Origins and Explanations

Modern wind manufacturing originated in Europe in the 1980s and 1990s, and continues to have a strong presence in Germany and to a lesser extent in Denmark and Spain. Generally, European manufacturing capacity levels have stabilized and in some cases eroded as demand in Western Europe has slowed, and new growth has emerged elsewhere in the world. More recently however, the offshore sector has begun to gain market share in Europe and is projected to have a larger manufacturing footprint in the coming years.

Beginning in the early to mid-2000s, the United States, China, India, and Brazil began increasing wind energy manufacturing capabilities. In the United States, manufacturing capacity was developed or repurposed from complementary industries as an increasing number of U.S. states adopted renewable energy portfolio standards (RPS), and steady extensions of a federal production tax credit supported robust growth, typically 5–10 GW per year with a peak of 13 GW installed in 2012 (Wiser and Bolinger 2015). The first components to be manufactured in the United States were technologically simple but large and relatively costly to transport, including towers and blades. Nacelle assembly capacity was followed by production of some subcomponents within the nacelles (e.g., bearings, gearboxes, electrical components), which came on line in anticipation of sustained North American wind energy growth. Today, U.S. production of current 2 MW and next generation 3 MW wind turbines is notable with capabilities present for blades, towers, generators, and gearboxes (GLWN 2014). Accordingly, current U.S. domestic content estimates include 80%–85% for towers, 50%–70% for blades and hubs, and more than 85% for nacelle assembly (Wiser and Bolinger 2015). At the same time, much of the nacelle internals are still imported and domestic content estimates for wind turbine equipment as a whole was estimated at approximately 40% in 2012 (Wiser and Bolinger 2015). Along with imports for nacelle internals generally, a persistent gap in the U.S. supply chain is the large structural castings used in the nacelle. At present U.S.-based manufacturers tend to import these castings from Asia and South America (GLWN 2014).

China is currently the largest manufacturer of wind power equipment in the world in terms of production capacity and output, supported predominately by its domestic demand (MAKE 2015b). A number of policies in the mid-2000s supported the establishment of a local Chinese wind power supply chain (Wang et al., 2012). The manufacturing sector has more recently undergone consolidation after years of overcapacity, but is projected to be robust based on a continued positive outlook of the Chinese demand market. Brazil has also observed the development of a sizable wind market built upon reverse auctions. In part as a function of increased demand, as well as strict domestic content requirements for wind equipment blade, tower, hub, and nacelle assembly facilities have been developed in Brazil. India also maintains gigawatt scale manufacturing facilities currently serving primarily domestic demand (Make 2015a). Canada, Mexico, and an array of other European and Asian economies also maintain some degree of manufacturing capacity; however, these more isolated pockets of manufacturing tend to focus on specific components for which they have a comparative advantage. For example, Mexico has relatively lower labor costs and close proximity to U.S. markets (Make 2015b).

To date, global wind power manufacturing has been driven by a combination of historical demand, projected future demand, and existing complementary production and fabrication industries. Europe and Germany in particular have had robust wind power demand in the past, and a sophisticated manufacturing sector that allowed Europe to be the primary source of wind turbine components through the early 2000s. Given their existing infrastructure and skill sets, some European manufactures have been able to stay intact as a continued source of supply for local European demand, to serve economies with somewhat variable demand (e.g., the United States) that might not always be met with domestic production, and to serve markets that are otherwise too small to justify local manufacturing capacity (e.g., Africa, the Middle East, and Central and South America). In contrast, manufacturing capacity in the United States, China, and Brazil has been established primarily due to high transport costs for large wind turbine components, and the relatively large quantities of current and anticipated domestic or regional demand. Moreover, in each of these economies, there was some ability to leverage existing manufacturing synergies within existing large and diverse industrial sectors.

7 | Manufacturing LED Packages

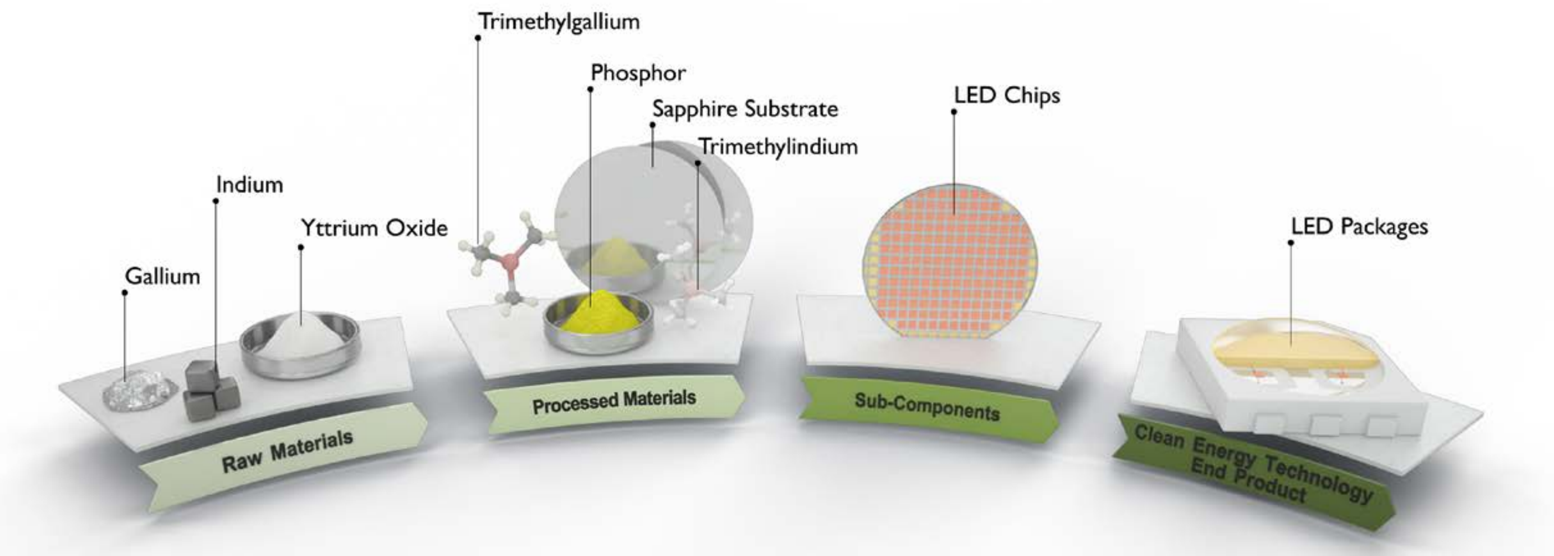


Figure 7-1. How LED package manufacturing process aligns with CEMAC benchmark framework. Illustration by Josh Bauer, NREL

The light-emitting diode (LED)—a solid-state semiconductor device that emits light when an electric current is passed through it—is one of today's most energy-efficient and rapidly-developing lighting technologies (DOE 2016c). We focus on the LED package as the end product of the supply chain framework (Figure 7-1), even though packages go on to be used in a variety of other products, including luminaires for displays, automotive headlights, and personal electronics.[19]

Manufacture of LED Packages

- Energy savings potential: All LED applications have the potential for energy savings; LED lighting has the potential to save 395 TWh by 2030 (Brodrick 2016).
- Revenue potential: Global Revenue from LED lighting systems is expected to total 216 billion USD between 2015 and 2024 (Navigant 2015).
- Innovation potential: Multiple opportunities for innovations that could lead to improvements in LED product efficacy, quality, and/or price exist. These include new chip and package designs, improvements

19. As part of its FY16 analysis portfolio, CEMAC evaluated the manufacturing cost and competitiveness of commercial LED luminaires, particularly the 2x2 troffers used almost exclusively in commercial lighting.

in package substrate, encapsulant, optics, and phosphor materials, as well as novel processing techniques, for example wafer bonding, substrate removal, and wafer-level processing. DOE LED lighting projects are working to achieve a market share of 84% of lumen-hour sales in the general illumination market by 2030 (Navigant 2014).

Key Findings

- The global market for LED packages used for general lighting was 7.9 billion USD in 2014 and estimated to grow to 12.7 billion USD in 2020 (Mukish and Virey 2014). Demand for LED luminaires, and thus for LED packages used in luminaires, is driven by regulated phase outs of incandescent lighting and the decline in LED luminaire prices.
- In 2014, LED package production was concentrated in Japan and South Korea, which together constituted more than 56% of total global package output. China and Taiwan are also significant producers, together constituting another 25% of total global production.
- Between 2015 and 2016, market oversupply drove average LED package selling prices down 30%–40% (LEDS Magazine, LEDSinside 2016). Consolidation of manufacturers is ongoing, and is expected to continue going forward.

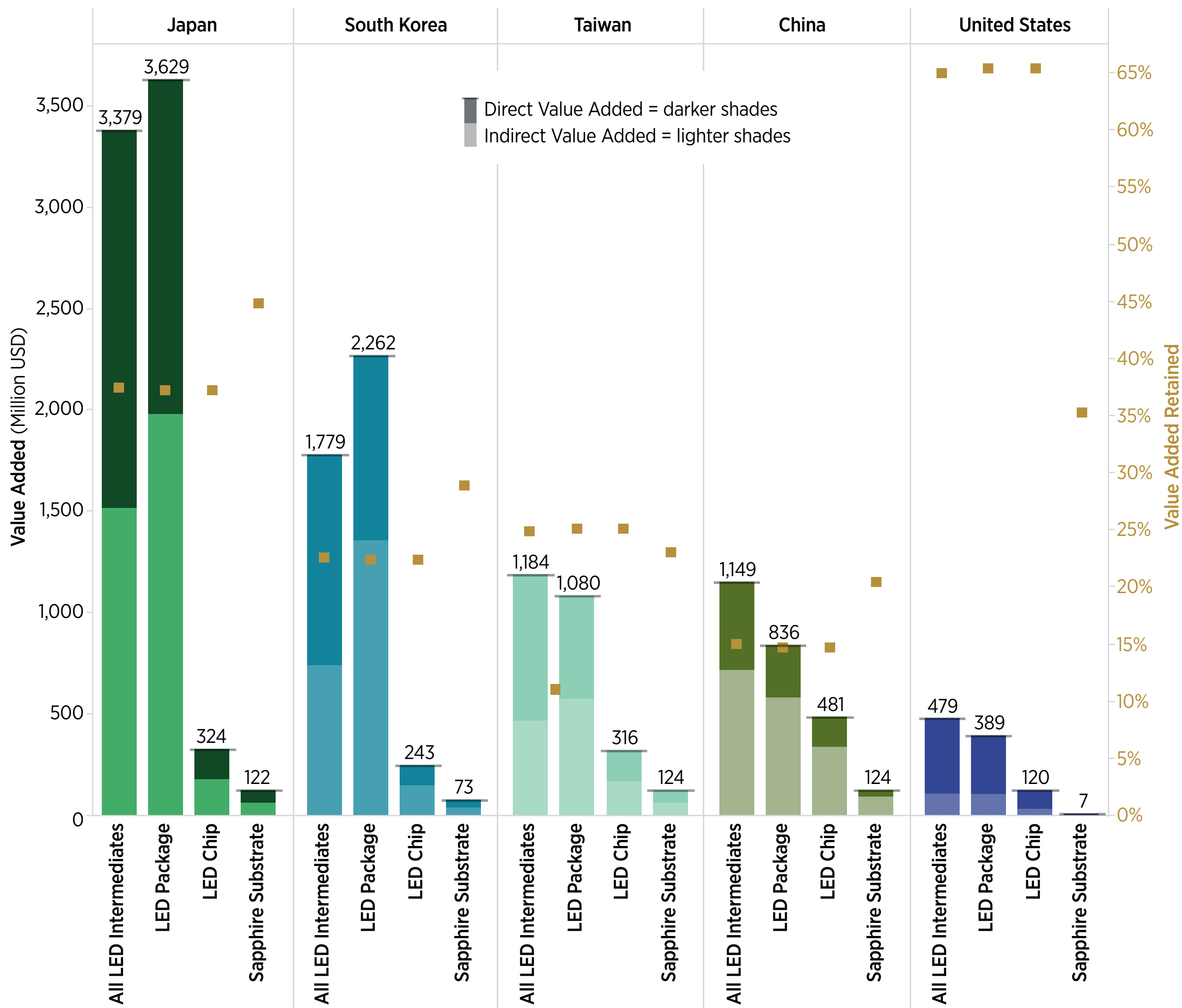


Figure 7-2. Value added by component for key LED components, 2014. Direct value added shown with dark shading and indirect value added shown with light shading. Direct value added retained indicated by squares (right axis). See methodology report for data quality discussion.

- Total value added from the production of LED packages, chips, and sapphire substrate in 2014 within the 12 economies included in this report is estimated at 8.6 billion USD, which is driven by 18.3 billion USD in production revenue.
- Across economies, value added followed production revenue. Japan, South Korea, Taiwan, and China produced the most LED packages and also the highest level of value added.
- Japan, Taiwan, and Malaysia had the most significant net exports in LEDs, maintaining 2.6 billion USD, 1.2 billion USD, and 1.4 billion USD balances of trade. These three economies and Canada (16 million USD) were the only economies in this report that were net exporters; all others had negative balances of trade.

Value Added

Total direct and indirect value added across all economies in this report was approximately 8.6 billion USD, with 4.8 billion USD in direct value added and 3.8 billion USD in indirect value added. With the exception of China, all LED-producing economies covered in this report show more direct than indirect value added.

As shown in Figure 7-2, the largest producers of LED packages and their upstream components were in Japan and South Korea, with 2014 sales of 5.0 billion USD and 4.6 billion USD, respectively. These were followed by Taiwan and China, each with 2.9 billion USD in revenue. Total value added levels follow production revenue, with Japan, South Korea, Taiwan, and China reporting highest value added.

Manufacturing of packages produced the highest levels of value added, 8.9 billion USD.[20] Chips follow with 1.5 billion USD. Sapphire substrates produce 0.5 billion USD. Japan and South Korea accrued the highest levels of total value added from package production. Figure 7-2 shows top producing economies and value added by component.

How economies rank in terms of value added follows the rank of their LED production levels. However, value added retained is also significant (see Appendix). Over all components U.S. LED component manufacturers retain an average of 65% of revenue, higher than all other economies. China is the lowest, with manufacturers retaining 15%.

Slightly different trends emerge when including indirect value added, or the supply chains for LED companies (See Appendix). The United States still had the highest percentage of direct and indirect value added per unit of production, although low production levels make this insignificant in terms of how the United States ranks in total value added levels compared to other economies. Among the top producers, Japan still led with 68% overall,[21] followed by Taiwan (41%).

Balance of Trade and Trade Flows

Raw materials, processed materials, LED chips, and LED packages are all traded globally. So-called rare earth materials, including the yttrium oxide used in many LED phosphors, are not actually rare. However, they are predominately mined in China. This has caused historical supply problems. In 2009 China imposed export restrictions, which caused prices to skyrocket. A WTO challenge led China to drop the restrictions in 2015 (Associated Press 2016). Some in the industry are exploring supply alternatives and design changes that could reduce the need for these elements.

The 12 economies in this report traded significant amounts of LEDs in 2014, primarily with each other (see Figures 7-3 and 7-4).[22] There were 16.3 billion USD in exports and 16.5 billion USD in imports, a -230 million USD balance of trade with the rest of the world. Asian economies were the largest net exporters, led by Japan (2.6 billion USD), Taiwan (1.2 billion USD), and Malaysia (1.4 billion USD). Net importers were not geographically concentrated. The United States led with a trade balance of -1.5 billion USD, followed by China (-1.3 billion USD), and Mexico (-1.2 billion USD).

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20. Value added from subcomponents does not sum to total value added. This is because total value added was controlled to avoid double counting while value added from subcomponents was not.

21. This percentage is lower than the 82% to 86% that Japan retained across packages, chips, and sapphire substrate because totals are controlled to limit double counting of indirect impacts. We did not apply the same controls to individual components.

22. International trade codes for lighting do not currently distinguish the type of lighting. Therefore it is not possible to explicitly distinguish import sources and export destinations LED lighting from more traditional lighting. Trade codes for LEDs for all applications differ across economies, but fall as a subset of 854140. For further information see CEMAC 2017.

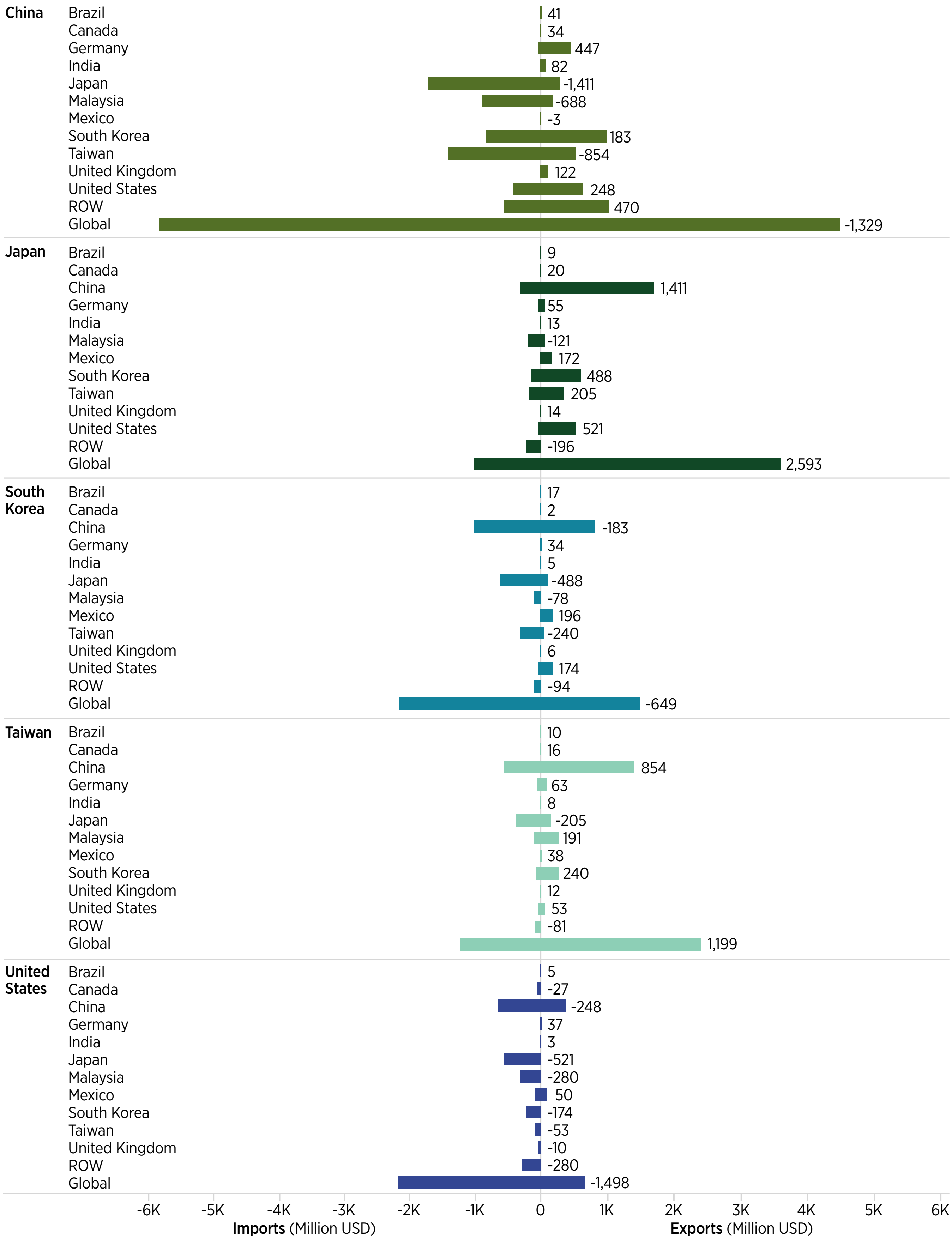


Figure 7-3. LED package and chip balance of trade (for all applications), 2014. See methodology report for data quality discussion.

Japan exported primarily to China (1.7 billion USD), South Korea (613 million USD), the United States (545 million USD), and Mexico (175 million USD).

The trade data shows that multiple economies are significant in the flow of product. Specifically, South Korea, Japan, China, and Taiwan are critical exporters of LED packages and die.

LED Market: Demand, Manufacturing Capacity and Production

The recent market explosion for packaged LEDs begun in 2009 and was driven by LCD display applications. This then triggered the vision for solid state lighting and caused aggressive investment in MOCVD tools. The result was significant global overcapacity and the average selling price of LED packages plunged 30% to 40% (Wright 2016; LEDinside 2015). The market then began to correct through consolidation, bankruptcies, and vertical integration.

The growth in general lighting is expected to lead to a CAGR 2014–2020 of 3.2%. The use of LEDs in TV has been falling and will likely continue to do so. The production volume for packaged LEDs is expected to grow 41% between 2014 and 2020. The expectation is that the Chinese market share will continue to grow and overall the industry will stabilize to a more normalized 80% equipment utilization rate (Mukish and Virey 2014).

Total global manufacturing of all LED packages was 15 billion USD in 2014 (Mukish and Virey 2014). Total global manufacturing of LED packages used in general lighting was approximately 7.9 billion USD in 2014 (Associated Press 2016). Demand, production and manufacturing capacity along the LED package manufacturing supply chain are summarized for the top five economies in Figure 7-5. For LED packages, demand and manufacturing capacity data were assumed to equal production, due to a lack of economy specific production data for LED packages. Demand for LED luminaires, and thus for LED packages used in luminaires, is driven by policy (regulated phase outs of incandescent lighting) and market forces (decline in LED luminaire prices). LED package production is concentrated in Japan and South Korea, which together constituted over 55% of total global package output. China and Taiwan are also significant producers, together comprising another 25% of total global production.

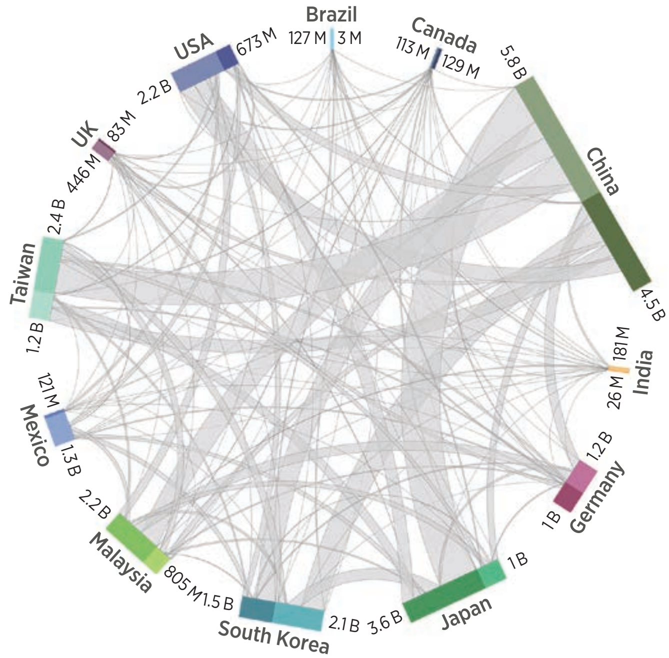


Figure 7-4. Flow of LED packages and chips (for all applications) between key trading partners, 2014. Darker shades represent exports; lighter shades represent imports.

LED Packages Manufacturing Process by Value Chain Link

Figure 7-1 illustrates the manufacturing supply chain for LED packages.

Raw Materials

Indium, gallium, yttrium oxide, and cerium (used in LED chips and packages) are critical to LED quality. Yttrium oxide and cerium are mined almost entirely in China (USGS 2016d, USGS 2016c). China is also the top producer of gallium and indium, but significant production also exists elsewhere globally (USGS 2016a, USGS 2016b). These materials are sometimes subject to tariffs or export quotas that can restrict supply or increase prices significantly. Note the yttrium and cerium are only required for certain types of phosphor materials, including YAG:Ce, a common phosphor material used for white LEDs. Researchers and members of industry are exploring potential options for reducing usage of rare materials, but most companies will likely not change the type of materials currently used in their process in the near-term. The LED raw materials are not included in the benchmark analysis due to a lack of data tracking where mined products are shipped.

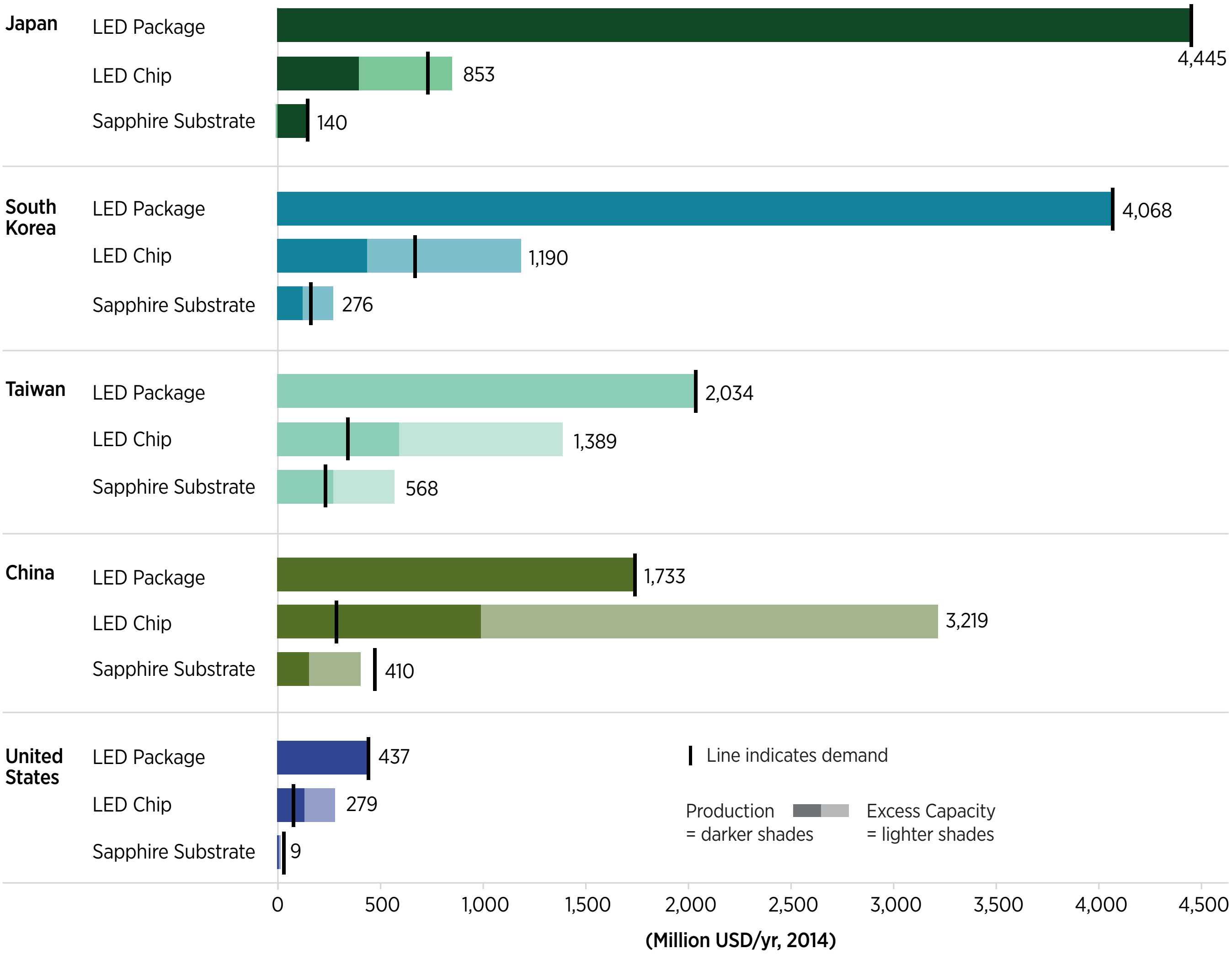


Figure 7-5. Market demand (line), manufacturing capacity (lighter shading, annotated), and production (darker shading) for commercial LED manufacturing supply chain, 2014

In Figure 7-5, we assume package demand in each economy is equal to production in that economy due to lack of data on demand for LED packages by economy. See methodology section for additional information and data quality discussion.

Processed Materials

Cerium-doped yttrium aluminum garnet (YAG:Ce) phosphor, the sapphire substrate, and precursor materials (Trimethyl Gallium (TMG), Trimethylindium (TMI)) for metal-organic vapor deposition have been unique and enabling products that allow for high performance and are used by the majority of manufacturers of LEDs for general lighting. Phosphors are heavily protected intellectual property governed by nearly 70 licensing and supply agreements) and are the subject of more than 40 litigation cases between 2000 and 2014). Because a company's competitive advantage is their differentiation through novel product characteristics and features (Sanderson and Simons 2014), patents can provide firms a significant manufacturing and sales advantage. However, some essential patents will expire in 2017, which could lead to LED package price decreases.

Subcomponents

LED chips (sometimes also referred to as die) are the components that actually produce light. The semiconductor chip consists of active layers that emit the light and the substrate, which supports the structure and upon which the active layers are grown. Their brightness and quality help determine the overall light quality and system efficiency.

End Product

The LED package houses the LED chips. For example, a package used for general lighting will typically contain between one to four chips. The LED package provides interconnection to the chips so that electricity can be applied from an outside source. Additionally, the package encapsulates and protects the LED chips, and includes the phosphors used to convert the light emitted from the chip into the appropriate color band. Each individual package can be relatively cheap (0.09 USD/package), but in commercial lighting, where multiple packages are used in each luminaire, packages can constitute a significant portion of the overall luminaire cost. The package design can also influence the overall luminaire design, for example type of driver implemented, how many packages are required, or which thermal management solutions are used.

The single largest application for LED packages in 2014 was lighting applications, followed by displays, mobile, signs, automotive, and other uses (Wright 2016). More than 120 companies are involved in LED package production, headquartered worldwide.

Manufacturing Capacity and Production: Origins and Explanations

LEDs were first used as an electronic component in 1968 (Schubert 2003). Early LEDs were used as indicators in electronic devices and in displays. As LEDs have improved with longer lifetimes, smaller size, and lower energy consumption, uses have expanded to include general lighting, consumer electronics, displays, signs, automotive, and other uses (Mukish and Virey 2014, Wright 2016).

- While LEDs were originally invented in the United States, Shuji Nakamura, from Japan's Nichia Corporation, made enormous scientific advances in LEDs in the early 1990s and catapulted Japan into a leading market position. Prior to 2010 Japan maintained this technical lead and captured more than 50% of market share (Su 2014). In 2010, lower-priced product helped Taiwanese, Korean, and Chinese firms capture market share, and Japan for the first time captured less than 50%.
- The Korean advances were led by Samsung and LG's development of LCD televisions with LED backlighting. South Korean companies further leveraged their brand advantage and with the support of the government adopted vertically integrated operations. This led to further market share gains.
- Taiwan's industry originally grew from international investment that established the first packaging plants. In the late 1990s Taiwan formed a collaborative which focused on integrating the entire LED value stream. This led to three main industrial clusters in Taiwan and created a pool of expertise in the LED and optoelectronic fields. Therefore, Taiwan firms reduced product development time and costs and slowly gained market share LED package and Sapphire substrate.
- China's LED industry grew dramatically between 2005 and 2007. In 2005, LEDs Magazine cited one Chinese firm. In 2007, the number jumped to 51 (Sanderson and Simons 2014). Government subsidies aided domestic firms with production equipment, land, leasing, and taxation (Schubert 2003, Mukish and Virey 2014, LEDSinside 2015).
- In 2014, LED package production was concentrated in Japan and South Korea, which together constituted more than 55% of total global package output. China and Taiwan together constituted another 25% of total global production. Taiwan's substrate expertise resulted in their 2014 production of 67% of sapphire substrates (Lin and Gueguen 2015).

More recently, the growth of the LED market has been driven by increased electricity costs coupled with the worldwide adoption of rules and regulations for energy efficiency, including the phase-out of incandescent lighting (En.Lighten 2016). Furthermore, Navigant Research reported that "LED prices have declined to a point where this type of lighting is becoming the economical choice in almost every application" (Navigant 2015).

BENCHMARKING CLEAN ENERGY MANUFACTURING
by Economy

8 | Benchmarking Clean Energy Manufacturing by Economy: Overview

This section summarizes the findings of each of the benchmarks across the economies that were assessed. The following chapters include more detailed results for each.

Value Added Benchmark Findings Across Economies

- China had 38.8 billion USD in total direct and indirect value added, which was supported by nearly 73.9 billion USD in revenue from production of wind turbine, c-Si PV, LED, and LDV Li-ion batteries. Japan had with 7.1 billion USD in value added. Value added was 6.2 billion USD in the United States.
- Despite leading in value added levels, China's value added retained was lower than most other economies. This is influenced by two factors: (1) how much businesses spend on production inputs that are purchased abroad, and (2) economy-wide value added as a portion of revenue. The United States led direct value added per unit of revenue (48%), and Brazil led direct and indirect value added per unit of revenue (82%).
- Clean energy manufacturing value added was the most significant relative to GDP as a whole in Taiwan, Malaysia, South Korea, and China.

Trade Benchmark Findings Across Economies

- Economies in Asia led net exports of c-Si PV, LED, and rechargeable Li-ion batteries. China, Taiwan, and Malaysia led net exports of PV; Japan, Taiwan, and South Korea led net exports of LEDs; China, South Korea, and Japan led net exports of rechargeable Li-ion batteries. Germany led net exports of wind components.
- No economy had positive trade balances across all technologies. The United Kingdom and the United States had negative balances across all technologies, but not all links in supply chain were negative.

Market (Demand, Manufacturing Capacity, Production) Benchmark Findings Across Economies

- LDV Li-ion cell demand is concentrated, with 95% of demand located in five economies—the United States, Japan, Germany, China, and the U.K.
- Wind turbine and solar module demand is less concentrated, though a small number of economies in both sectors still constitute a disproportionate share of total global demand.
- Wind turbine and c-Si PV module production is heavily concentrated in China. Wind turbine production outside of China is concentrated in the U.S., Brazil, India, and Germany. PV module production outside of China is generally much more disaggregated, although Malaysia and Japan host the next largest shares of module production.
- Production of both LED Packages and LDV Li-ion cells is more globally distributed, but practically all global production for these end products occurs in only four or five economies. LED Packages are produced in Japan, South Korea, Malaysia, Taiwan, and China, while LDV Li-ion cell production is concentrated in Japan, South Korea, the United States, and China.
- In general, different supply chain activities within each technology appear to be nationally co-located. Economies hosting significant shares of end product production also appear to produce a commensurate share of upstream subcomponent and processed materials.
- The average manufacturing capacity utilization for each technology end product appears to be relatively low. Global average utilizations are 62%, 55%, 37%, and 41% for wind turbine components, c-Si PV module, LED Chip, and Li-ion cell manufacturing, respectively.

9 | Brazil: Clean Energy Manufacturing Profile

Brazil has the world's sixth largest economy, and the largest economy in Latin America, with a GDP of about 2,417 billion USD in 2014. Building on the domestic market, Brazil has established itself as an important manufacturing base for clean energy, particularly for wind equipment. Brazil had a cumulative 15 MW of PV and 6 GW of wind generation installed by 2014 (IRENA 2015b). Brazil has experienced an economic downturn since 2014, leading to high interest rates, a weak currency, and struggles within the energy sector. The data presented here do not reflect the economic conditions since 2014.

Key Findings

- In 2014, manufacturing of wind turbine components supported 2.4 billion USD in value added (direct and indirect) in Brazil. The other technologies analyzed in the report (c-Si PV, LED packages, and Li-ion battery cells) did not contribute to Brazil's value added.
- Brazil has established itself as an important manufacturing base for wind turbine components, accounting for 4% of global manufacturing capacity of nacelles and 9% for blades.
- For the four technologies considered, in 2014, exports totaled 29 million USD and imports totaled 727 million USD, leaving Brazil with an overall negative balance of trade (-698 million USD).[23]

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 2.9 billion USD in revenue from manufacturing of wind turbine components supported 2.4 billion USD of value added (1.0 billion direct, 1.4 billion indirect) in Brazil (see Figure 9-1). Brazil generated no value added from the manufacturing of PV modules, LED packages, and Li-ion battery cells for vehicles.

Across the supply chain, manufacturing of wind turbine components generated more indirect than direct value added.

Wind component manufacturers in Brazil retain relatively high levels of direct value added compared to other economies—35% for Brazil and 30% for the 12-economy average. The 12-economy average for all technologies included in this analysis is 25%.

Also shown in Figure 9-1, Brazil is first among economies studied in this report in total (direct and indirect) value added retained at 82%. Brazil also has high value added as a portion of overall economic activity (gross output) across all industries economy-wide.

Economy

- GDP (nominal USD, 2014): 2,416 billion (World Bank 2016)
- Economy-wide value added contribution: 49% of all economic activity (gross output) in 2014
- Import contribution: 4% of gross output, 2014
- GDP growth rate (five year average 2010–2014): 3.3% (World Bank 2016)
- Manufacturing, value added (% of GDP 2013): 12.3 (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.7

Trade

- Total imports (USD, 2014): 229 billion (WITS)
- Total exports (USD, 2014): 225 billion (WITS)
- Main trading partners: China, United States, Germany, Argentina (exports)
- Main trading partners (2015): China, United States, Germany, Argentina (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 134 GW (EIA Beta 2015)
- Renewable share (excluding large hydro): 12.3% (EIA Beta 2015; IRENA 2015a)
- Total investment in clean energy (USD, 2014): 6.4 billion (BNEF 2016)

RE and EE Targets

- National voluntary non-hydro clean energy generation target: 20% by 2030

23. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

The relatively greater economy-wide, direct, and indirect impacts of clean energy manufacturing are driven by characteristics of Brazil's national economy. Brazil has the lowest percentage of imports as a component of economic activity of the economies in this report, well-developed domestic supply chains, and high value added. Domestic supply chains mean that manufacturers rely less on imports; businesses that supply goods and services to manufacturers, then, support value added in Brazil. The portion of revenue that leaves the economy to pay for imported inputs is 4% compared to the 12-economy average of 11%. Value added across all industries as a portion of revenue economy-wide is 49%, greater than the 12-economy average of 46% (OECD 2015).

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

Brazil's *Plano Brasil Maior* (Bigger Brazil) industrial policy aims to create favorable tax advantages for Brazilian manufacturers and reduce financing and energy costs (IRENA 2015b). Under the plan, the Brazilian government hopes to address legal, financial, and infrastructure barriers that have historically undermined the competitiveness of Brazilian companies in domestic and international markets (World Economic Forum 2016, Deloitte 2016).

With respect to clean energy manufacturing, Brazil has established itself as an important manufacturing base for

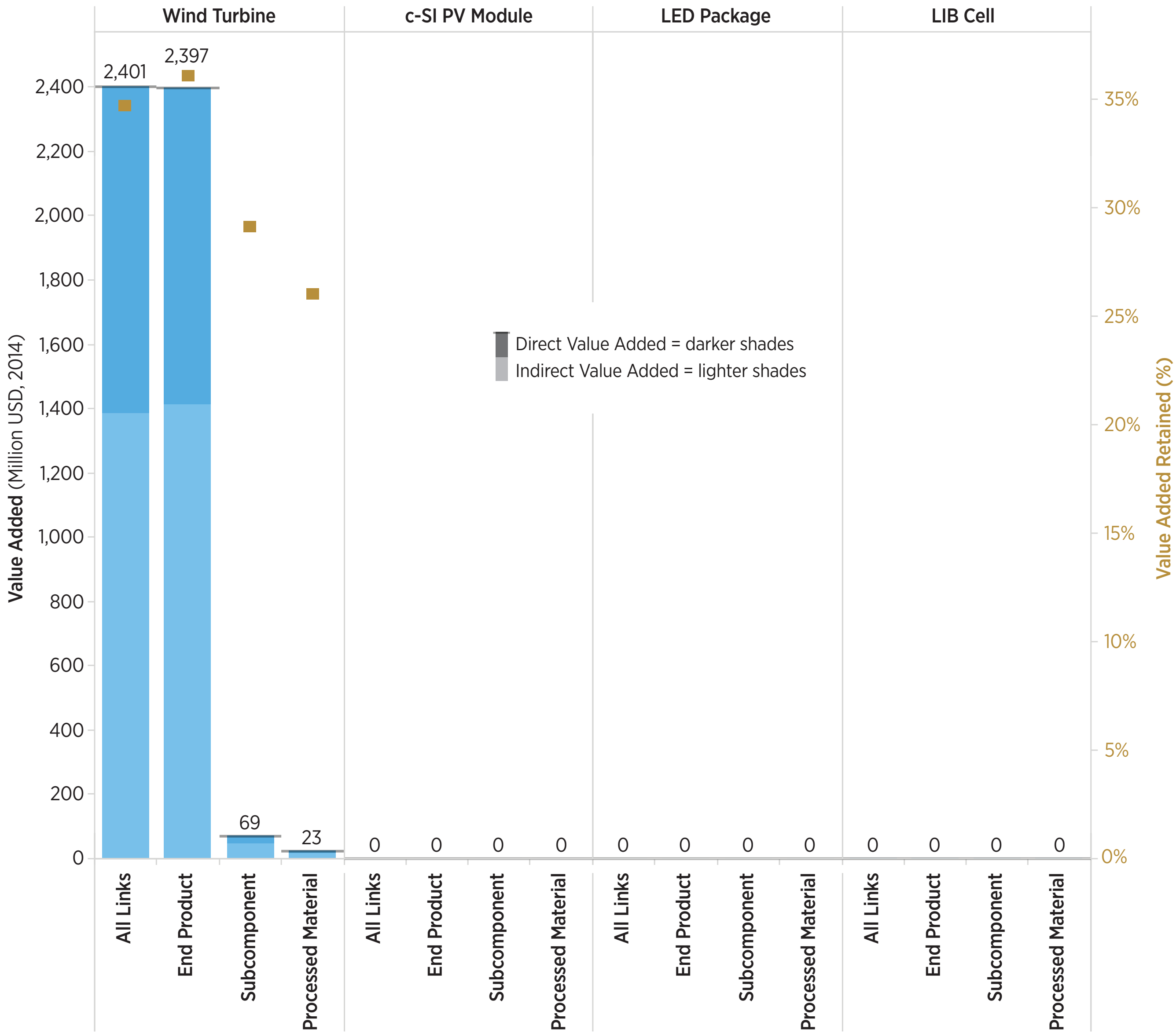


Figure 9-1. Brazil's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

wind turbine components. The Brazilian development bank, Banco Nacional de Desenvolvimento Economico e Social (BNDES), placed strict local content requirements for wind equipment as a prerequisite for favorable financing. Initially, BNDES required a minimum of 60% of the turbine to be produced domestically. The requirement tightened in 2013. BNDES now requires wind towers, blades, and hub to be produced in Brazil and for the nacelle assembly to take place in Brazil. This has led to the rapid development of a domestic supply chain. Nine international turbine manufacturers have set up production facilities in Brazil to access the market. Domestic and international blade, tower, and other component manufacturers have also built production capacity to complete the supply chain.

In 2014, Brazil's manufacturing capacity included 3,800 MW of nacelle capacity (4% of the global total), 7,900 MW of blade capacity (9% of global), 2,600 MW of tower capacity (4% of global), and 1,600 MW of generator capacity (3% of global).

Brazil was a large demand market for wind turbines in 2014, totaling 2,500 MW (5% of total global demand). Brazil was the third-largest single economy market in 2014, behind China and the United States

Figure 9-2 shows Brazil's 2014 demand, manufacturing capacity and production for wind turbine components.

Brazil did not host any significant PV module, LED packages or Li-ion battery manufacturing capacity in 2014. In 2014, domestic PV demand was minor at 130 MW,

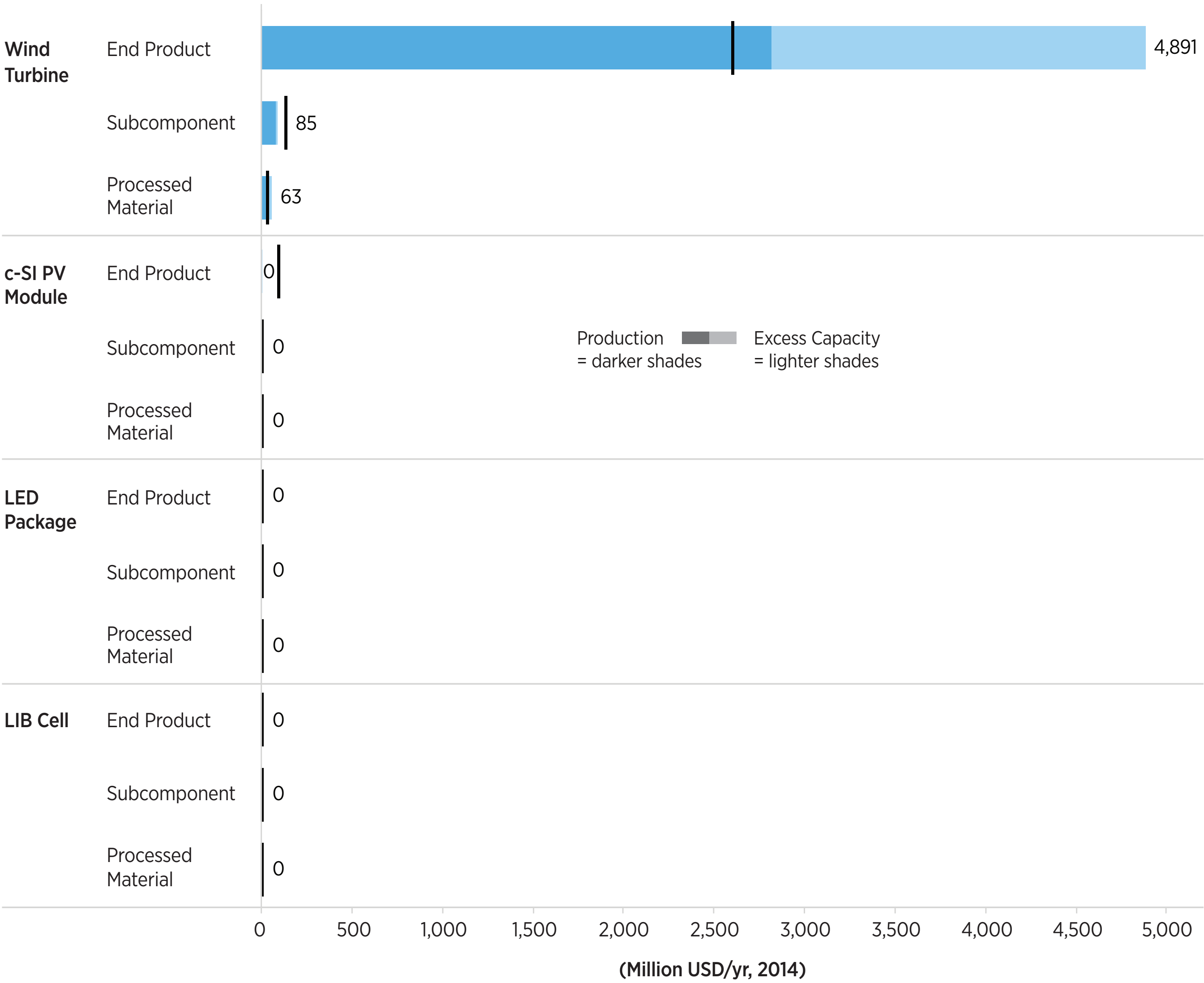


Figure 9-2. Brazil's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, 2014. See methodology report for data quality discussion.

but the market appears set to grow, with the award of 31 proposed projects in 2014 totaling 890 MW (Roselund 2014). BNDES offers low-cost financing for PV projects, with the requirement that an increasing number of components be manufactured domestically to 2020 (BNDES 2016). With this policy, BNDES hopes to attract manufacturing investment for PV.

Trade Landscape: Balance of Trade and Trade Flows

Brazil is a founding member of the Southern Common Market (MERCOSUR), and is included in preferential trade agreements with a number of Central and South American economies. Through MERCOSUR, Brazil also has preferential trade agreements with a number of other economies around the world. In addition to the *Plano Brasil Maior*, which supports development of foreign trade policies, Brazil promotes exports through the Export Financing Program (PROEX) and the export credit schemes under the BNDES-exim program to enhance the competitiveness of export-oriented companies, in particular small-scale enterprises.

In 2014, Brazil maintained a negative balance of trade across all benchmarked clean energy technologies, although these balances were relatively low due to low levels of both imports and exports. Balance of trade and trade flows for the supply chain links for which trade data are available are presented in Figures 9-3 through 9-7.

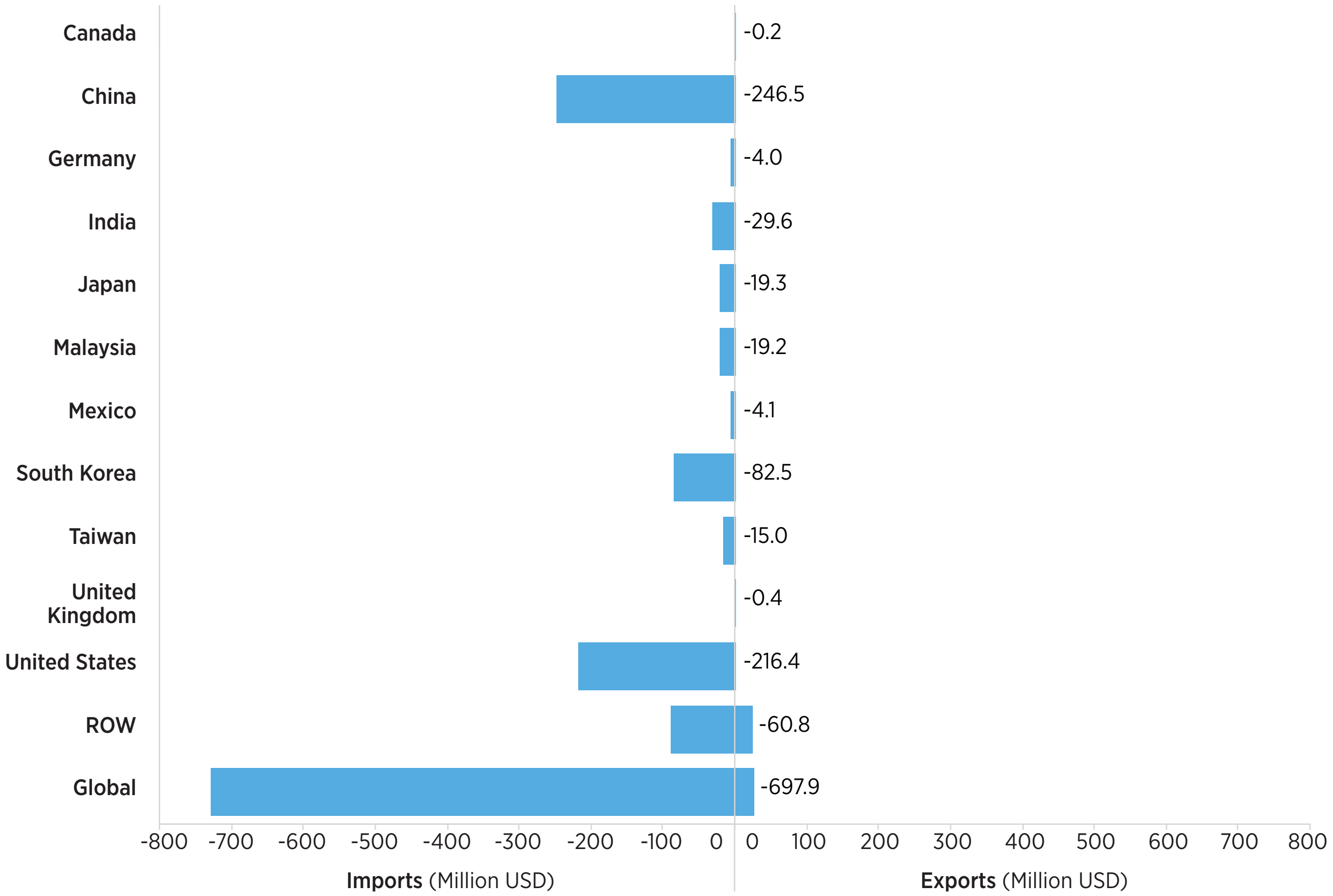


Figure 9-3. Balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated.

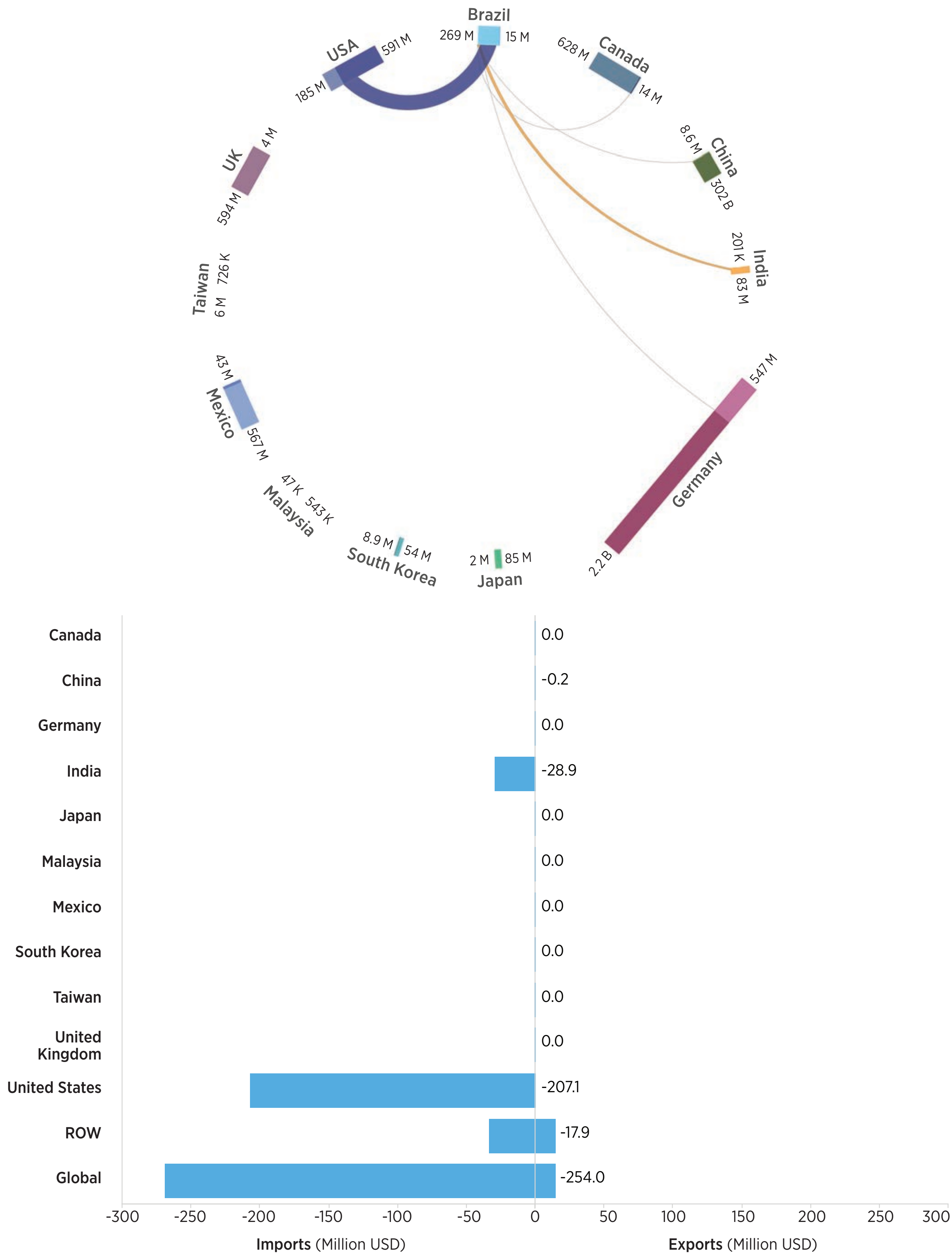


Figure 9-4. Brazil's 2014 trade flows and balance of trade for wind turbine generator sets. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

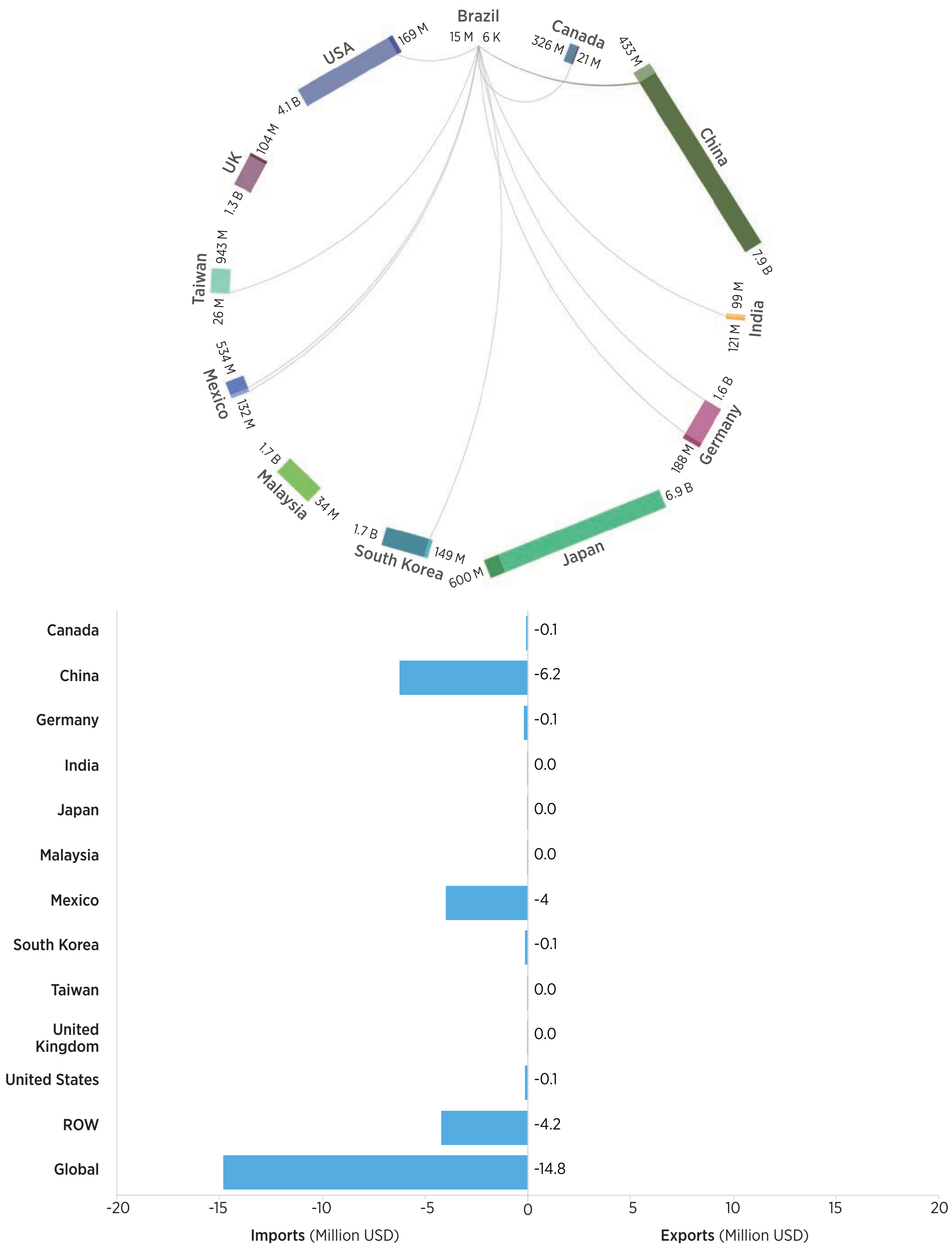


Figure 9-5. Brazil's 2014 trade flows and balance of trade for PV modules. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

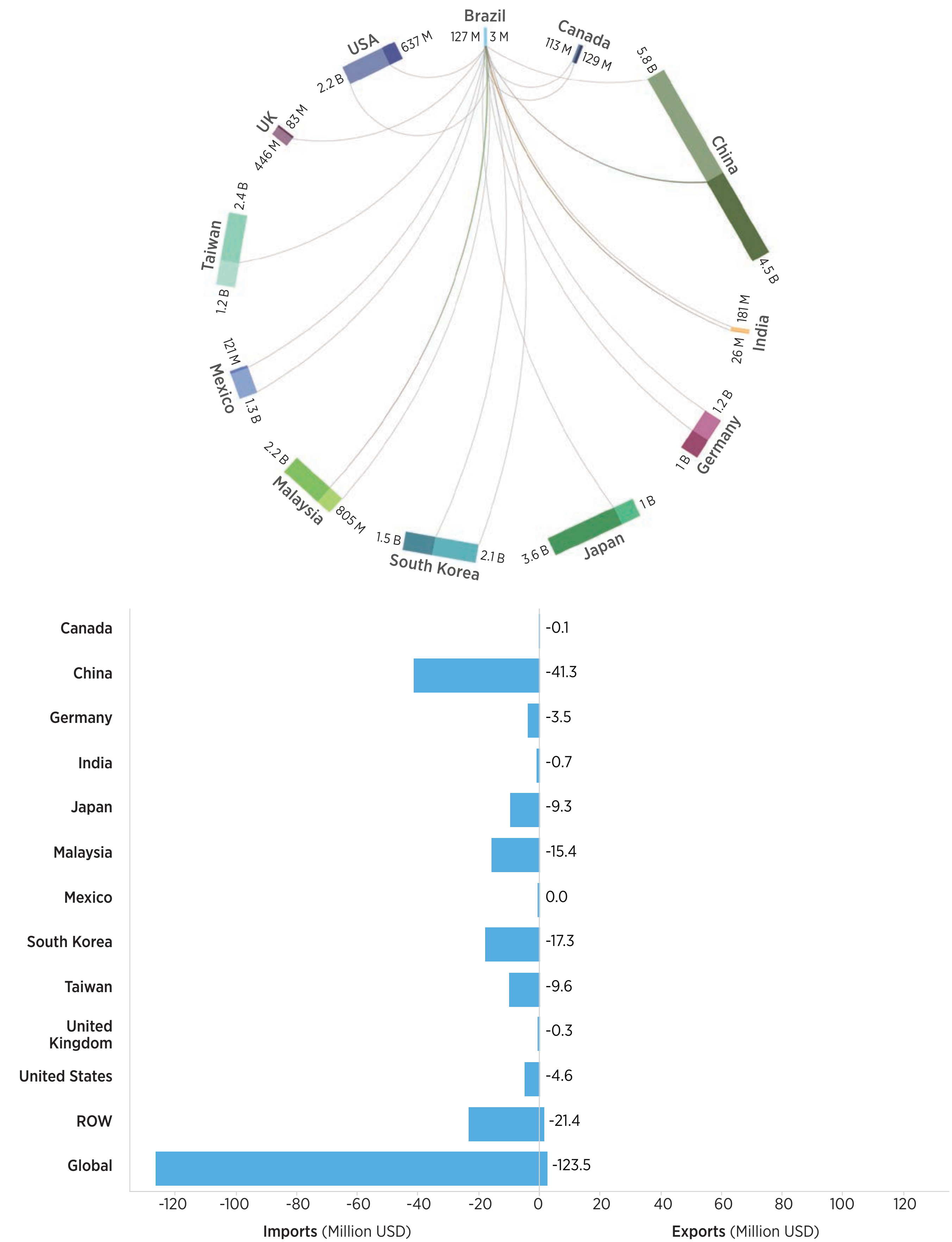
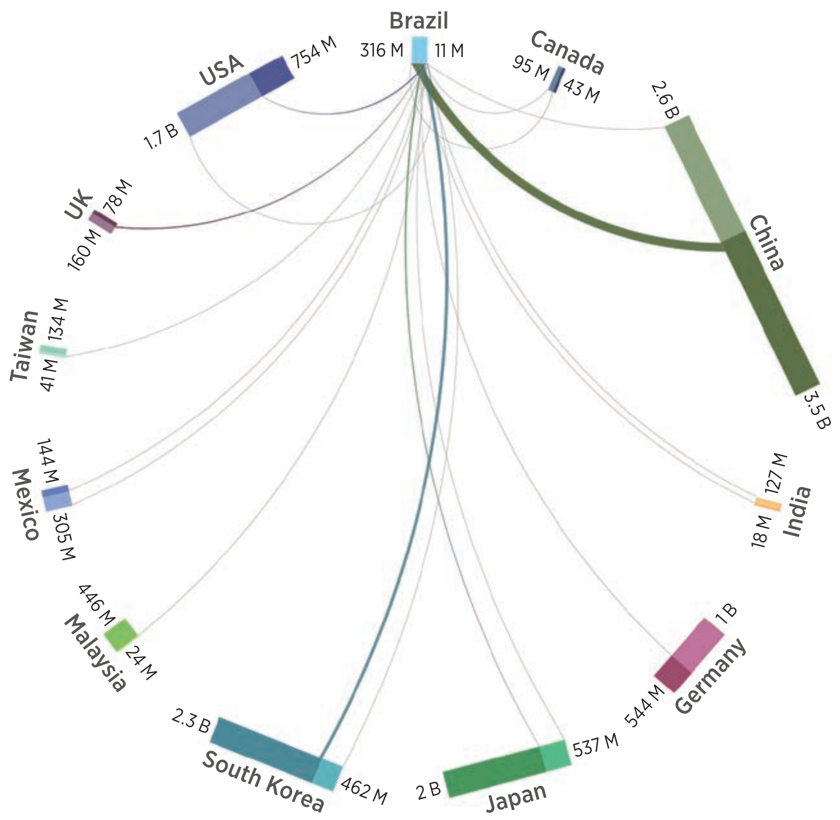


Figure 9-6. Brazil's 2014 trade flows and balance of trade for LED packages. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



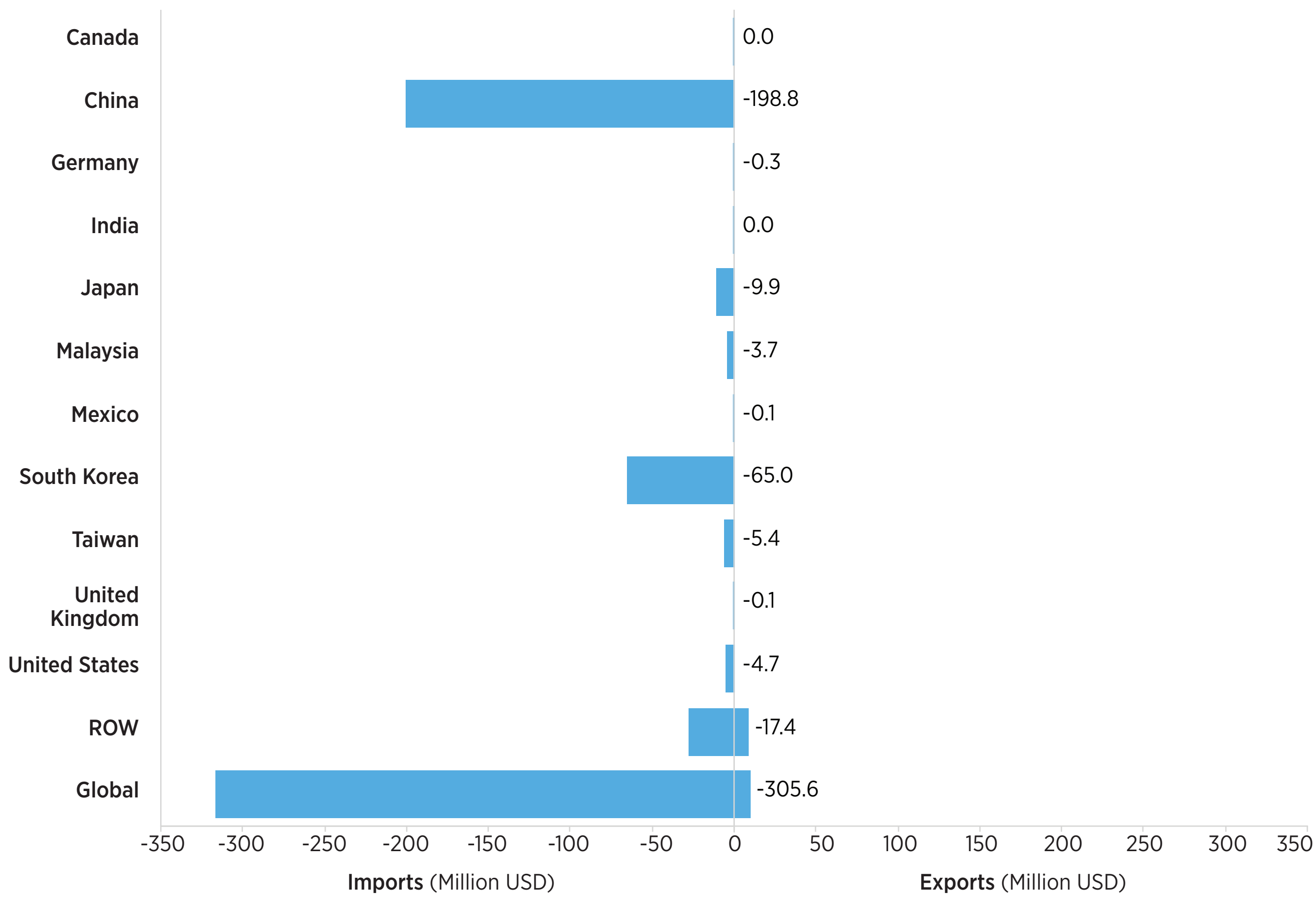


Figure 9-7. Brazil's 2014 trade flows and balance of trade for Li-ion battery cells. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

10 | Canada: Clean Energy Manufacturing Profile

Canada has the world's tenth largest economy and a GDP of almost 1.8 trillion USD. The energy sector has been a primary driver of Canada's economy for many decades thanks to an abundance of diverse energy sources including coal, conventional and unconventional oil and natural gas, hydro, biomass, wind, and solar. Canada is a world leader in the production and use of renewable energy, which currently accounts for about 19% of the nation's total primary energy supply (Government of Canada 2016). Canada had a cumulative 1.7 GW of PV and 9.7 GW of wind generation installed in 2014 (IRENA 2015a). In general, provincial rather than national-level laws, policies, and incentives have driven deployment of clean energy technologies in Canada (Valentine 2010).

Key Findings

- In 2014, manufacturing of wind turbine towers and blades, PV modules, and cathode materials for Li-ion battery cells contributed 660 million USD in value added (direct and indirect) to Canada's economy. This was primarily from wind (353 million USD) and c-Si PV (303 million USD), although automotive battery cell production contributed 4 million USD.
- Canada's PV module manufacturers achieved an average utilization rate of 93%, well above the global average of 55% for the other economies included in this analysis. For this report, wind production was assumed to equal manufacturing capacity due to a lack of data. Canada was not home to any significant Li-ion cell or LED package manufacturing.
- For the four technologies considered, in 2014, exports totaled 213 million USD and imports totaled 1.3 billion USD, leaving Canada with an overall negative balance of trade (-1.1 billion USD).[24] The top trading partners for Canada were the United States, Germany, and China. Canada's lead export among clean energy manufacturing products was LEDs for all applications while its top import was wind generator sets.

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 1.0 billion USD in revenue from manufacturing of PV modules, wind turbine components, and Li-ion battery cells for vehicle manufacturing supported 660 million USD of value added (430 million USD direct VA and 230 million USD indirect VA) in Canada (see Figure 10-1).

Across the technology supply chains, the highest total value added came from wind components (353 million USD) and c-Si PV components (303 million USD); Li-ion battery cells for automobiles supported 4 million USD.[25]

Economy

- GDP (nominal USD, 2014): 1,785 billion (World Bank 2016)
- Economy-wide value added contribution: 54% of all economic activity (gross output) in 2014
- Import contribution: 10% of gross output, 2014
- GDP growth rate (five year average 2010–2014): 2.5% (World Bank 2016)
- Manufacturing, value added (% of GDP 2012) : 11% (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 1.1

Trade

- Total imports (USD, 2014): 463 billion (WITS)
- Total exports (USD, 2014): 474 billion (WITS)
- Main trading partners (2014): United States 53.3%, China 12.3%, Mexico 5.8% (exports) (CIA 2016)
- Main trading partners: United States 76.7%, China 3.9% (imports)

Energy Sector

- Total installed generation capacity: 102 GW
- Renewable share (excluding large hydro): 13.1% (BNEF 2016; IRENA 2015a)
- Total Investment in Clean Energy: 8.7 billion USD (BNEF 2016)

RE and EE Targets

- No national level targets

24. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

25. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

Manufacturing of wind turbine components[26], PV modules, and Li-ion batteries for automobiles generated more direct than indirect value added across the supply chain.

Clean energy manufacturers in Canada retain relatively high levels of direct value added compared to other economies—42% for Canada and 25% for the 12-economy average. This is consistent across all of the clean energy technologies considered, ranging from 39% for batteries to 43% for wind. Solar PV was 41% (Figure 10-1).

When comparing total (direct and indirect) value added retained, Canada ranks fifth of the economies in this report, with clean energy manufacturers and their greater supply chains supporting 65% of Canada's total value added as a portion of clean energy manufacturing revenue.

The relatively greater economy-wide, direct, and indirect impacts of clean energy manufacturing are driven by characteristics of Canada's national economy. Canada has relatively low imports (import expenditure in Canada constitutes 10% of gross output, as opposed to the 12

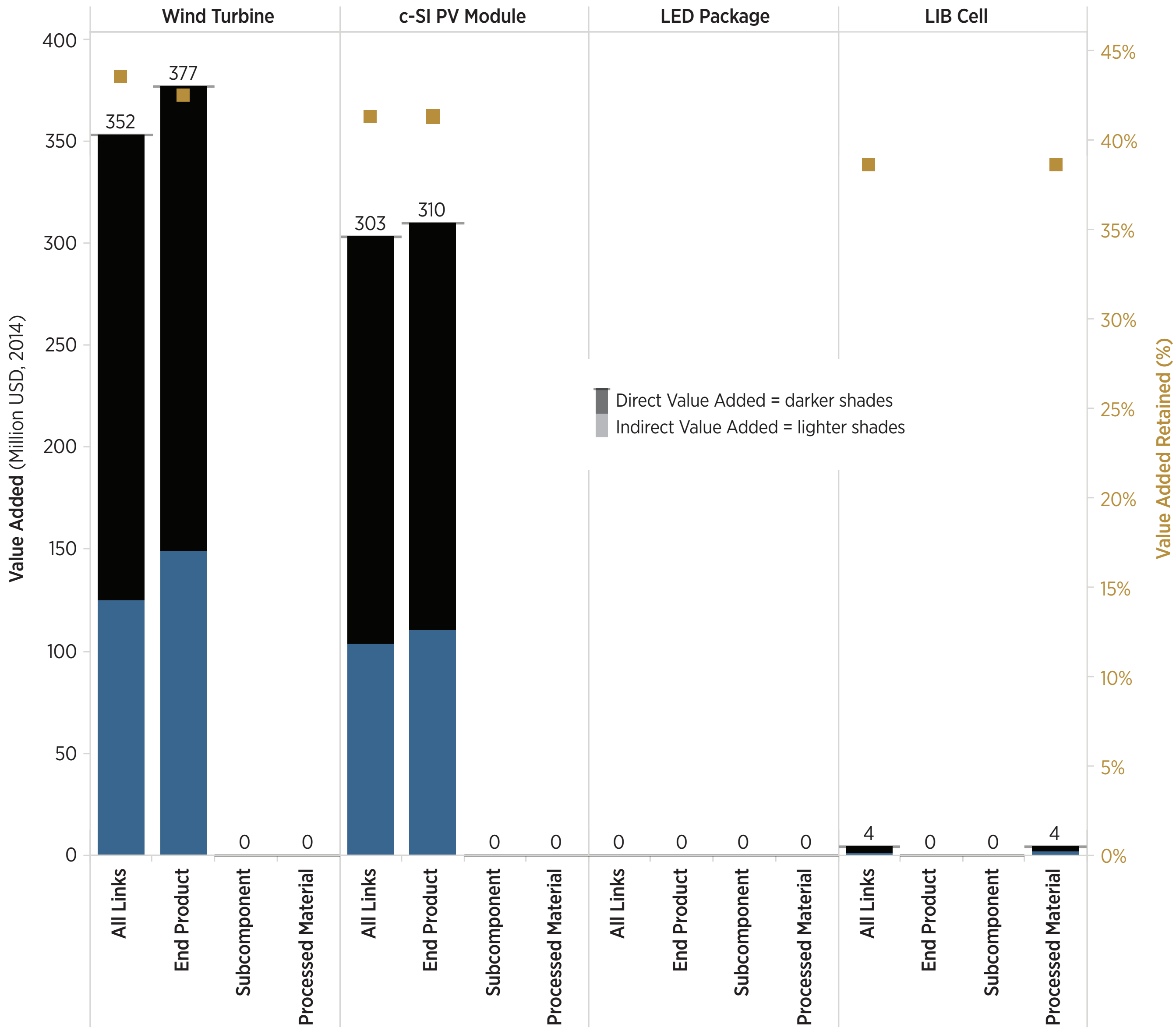


Figure 10-1. Canada's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

26. Value added from wind blade manufacturing only includes land-based wind.

economy average of 11%), well-developed domestic supply chains, and high value added. Of the economies in this report, Canada had the third highest value added as a percentage of gross output at 54%, behind only Mexico and the United States. Domestic supply chains mean that manufacturers rely less on imports; businesses that supply goods and services to manufacturers, then, support value added in Canada. This reflects lower imports as well as more value added supported by those businesses economy-wide.

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

The manufacturing sector contributed an average of 11% to Canada's GDP between 2008 and 2012 (World Bank 2016). Assuming 11% for 2014, the contribution to GDP from manufacturing would have amounted to 196 billion USD. In 2014, Canada's top three manufacturing sectors were transportation equipment, food processing, and petroleum and coal products (Ministry of Industry 2015).

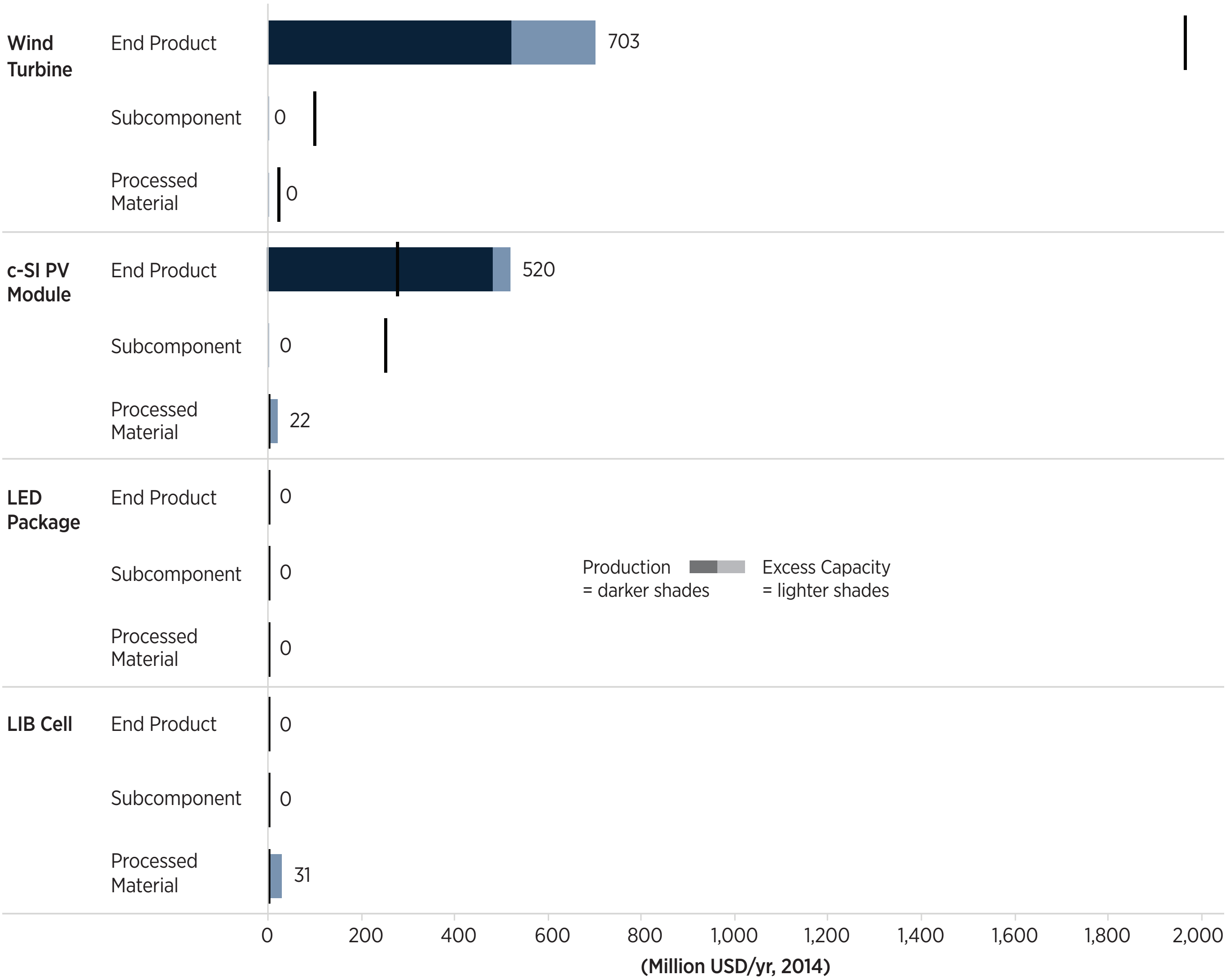


Figure 10-2. Canada's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, 2014. See methodology report for data quality discussion.

The Canadian government is working to ensure that domestic manufacturers have new opportunities to grow and expand through its Global Markets Action Plan, which calls for expanding trade with markets that hold the greatest potential for Canadian manufacturers. The 2013 plan prioritizes 22 sectors, including sustainable technologies, where Canada has a strong competitive advantage and plans to develop strategies to help these sectors grow. In addition, Canada has cut federal taxes to support domestic manufacturing. In eliminating all remaining tariffs on imported machinery and equipment and manufacturing inputs, Canada is now the first tariff-free zone for industrial manufacturers in the Group of 20 industrialized nations. At the subnational level, Quebec and Ontario provinces have established domestic content requirements for renewable technologies.

In 2014, Canada hosted manufacturing capacity for wind blades, towers and generators; PV modules, and Li-ion cell cathode materials. Canada did not manufacture LED packages in 2014. Figure 10-2 shows Canada's 2014 manufacturing capacity, production, and demand for the four technologies in this analysis.

Along the wind turbine supply chain, Canada hosted a manufacturing capacity that included 1,100 MW of blade (1% of total global capacity) and 2,100 MW of tower (3%) manufacturing in 2014. Canada is home to a small amount of PV module manufacturing capacity, which was initially established to meet provincial content requirements set forth in Ontario's feed-in tariff program. In 2014, Canada hosted 730 MW of module capacity, and produced 680 MW of modules, well below the output of other economies in this report, excluding those nations with no capacity. In 2014, Canada was home to a minor amount of automotive battery processed materials manufacturing: about 0.5 GWh of annual cathode materials manufacturing capacity.

Canada's PV module manufacturers achieved an average utilization rate of 93%, well above the global average of 55%. For this report, wind production was assumed to equal manufacturing capacity due to a lack of data.

On the demand side:

- Annual wind turbine demand reached 1,900 MW in 2014, making Canada the sixth largest demand market of the economies in this report. Cumulative capacity at the end of 2014 totaled 9,700 MW. Installed wind turbine capacity in Canada has expanded rapidly in recent years and is forecast to continue to grow at a fast pace due to increased interest from electricity producers and governmental initiatives.
- Canada's demand for PV has increased in recent years, although it remains relatively small in terms of the global market. Canada installed 390 MW of PV in 2014, about 1% of total global demand. CEMAC estimates demand will grow at an average of 12% annually between 2015 and 2020 (Based on data from BNEF, GTM, and Navigant).
- Canada did not have any significant demand for LDV Li-ion battery cells in 2014, suggesting automotive Li-ion battery packs were not assembled in the economy at the time.

Trade Landscape: Balance of Trade and Trade Flows

Canada maintains an open economy and has free-trade agreements with 44 economies, including the Canada–European Union Comprehensive Economic and Trade Agreement and the Canada–Korea Free Trade Agreement, Canada's agreement with an Asian economy (Government of Canada 2015). Exports of goods and services accounted for 31% of Canada's GDP in 2014. Canada is heavily reliant on the United States as its major trade market and has a narrow export product base, mainly energy and mineral products, and transportation and vehicles. In the renewable energy sector, the U.S. Department of Commerce estimates that, during 2016, Canada will account for nearly one-fourth of all U.S. exports (ITA 2016). Figures 10-3 through 10-7 show balance of trade in the selected clean energy technologies as a group and individually.

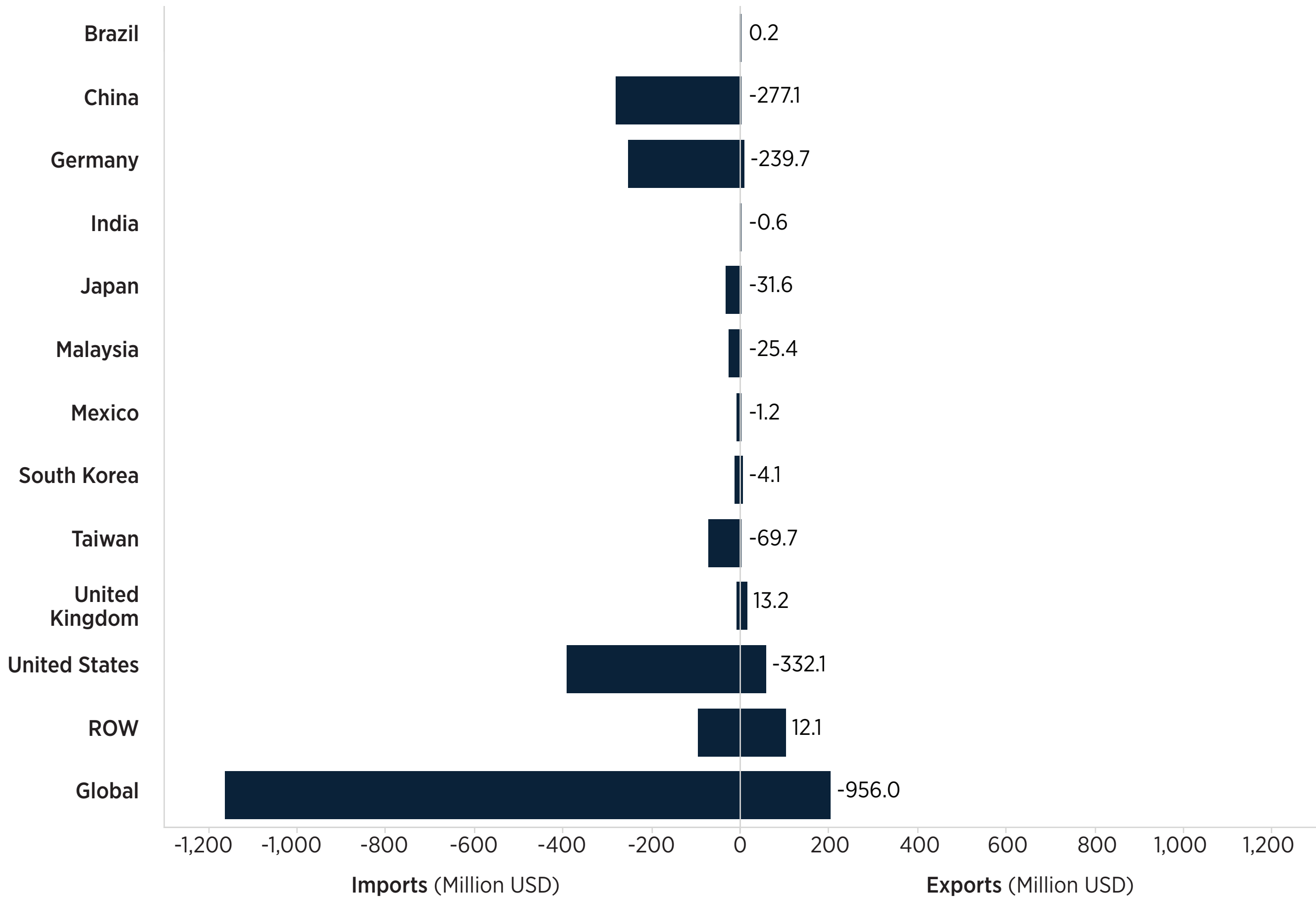


Figure 10-3. Canada's balance of trade aggregated for four clean energy technology (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

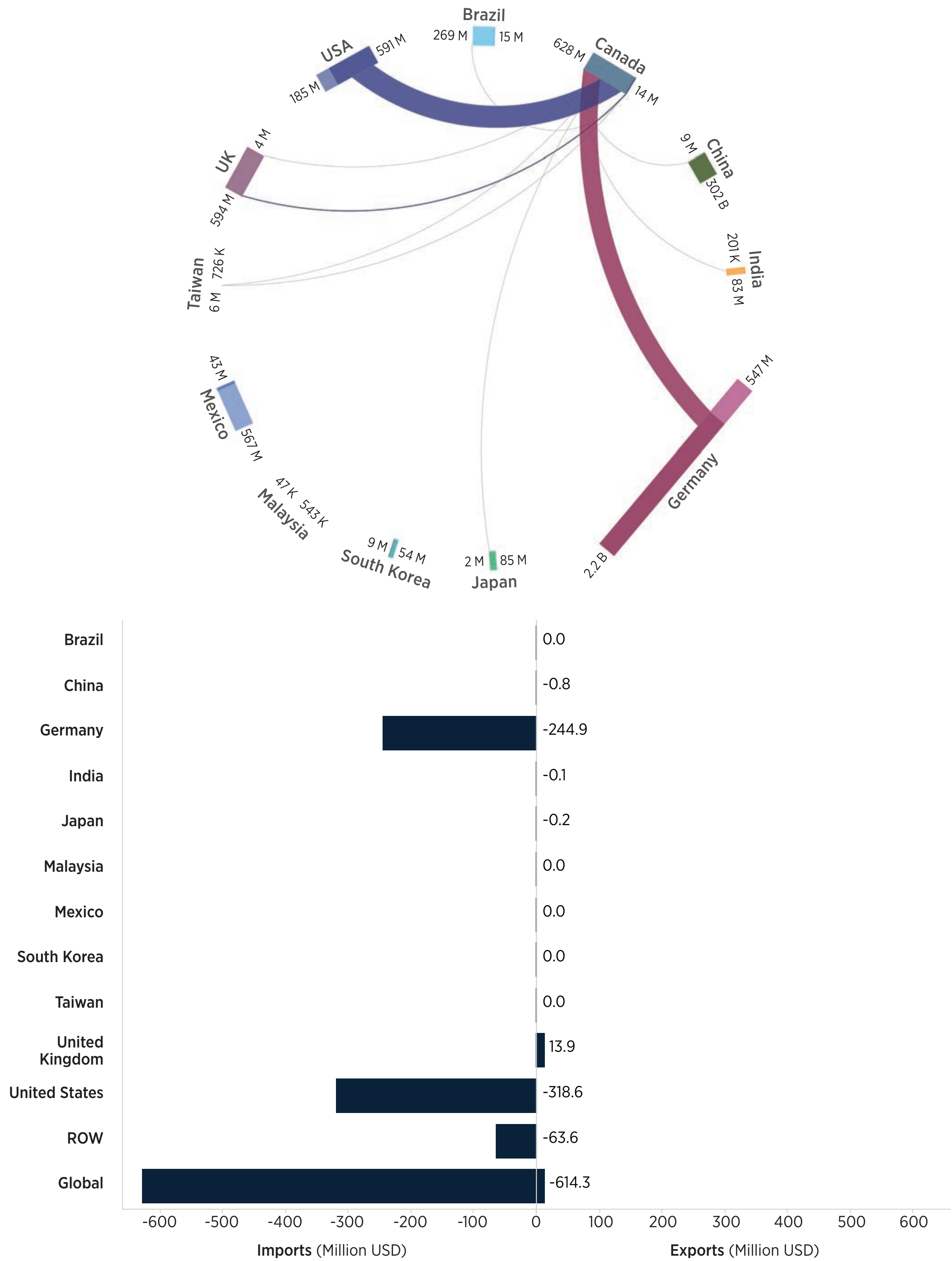


Figure 10-4. Canada's 2014 trade flows and balance of trade for wind turbine generator sets. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

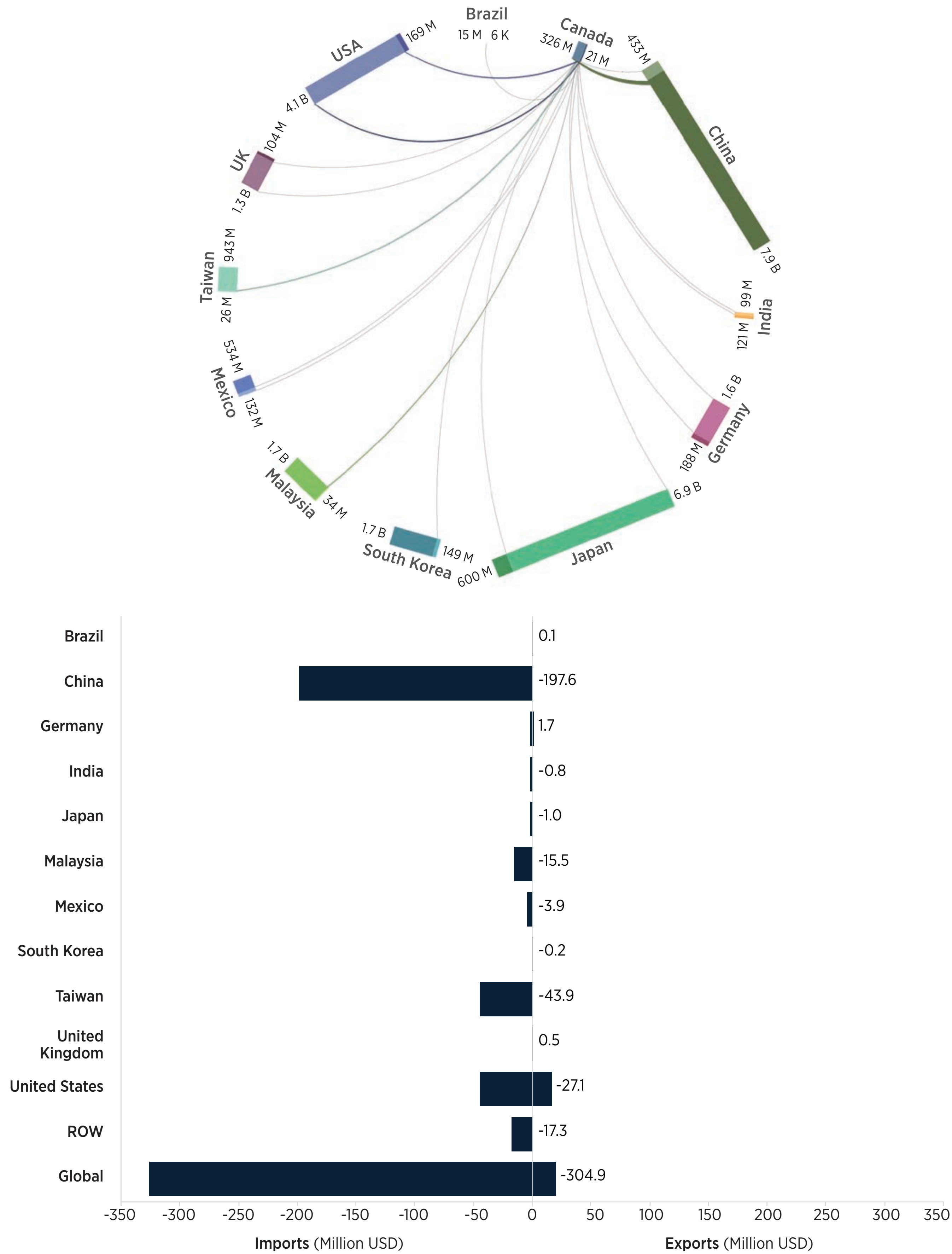
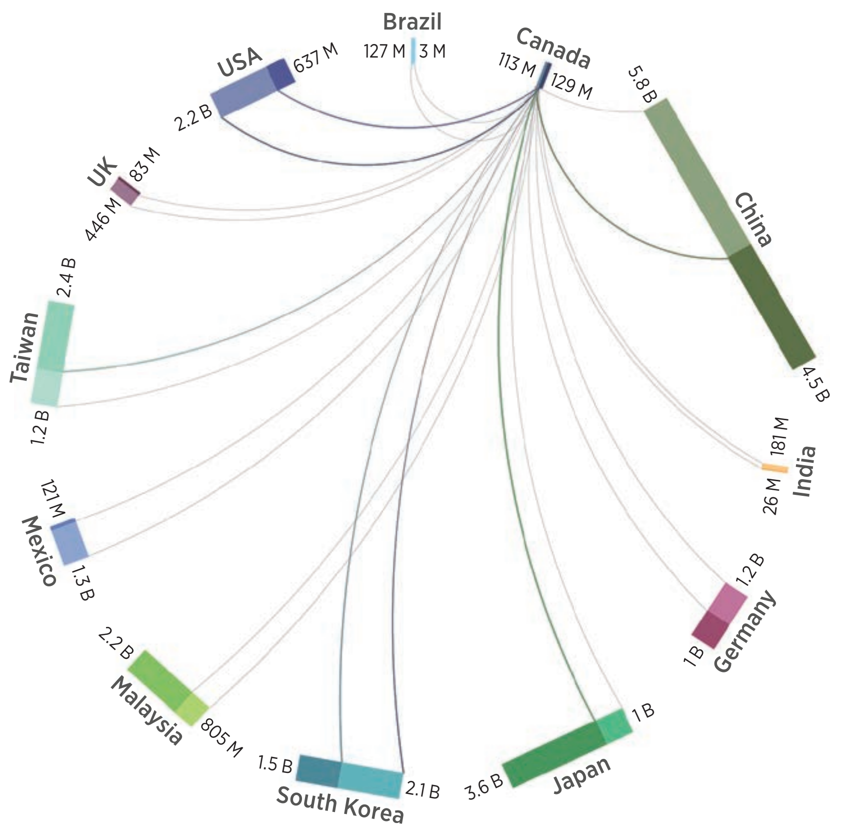


Figure 10-5. Canada's 2014 trade flows and balance of trade for PV modules. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



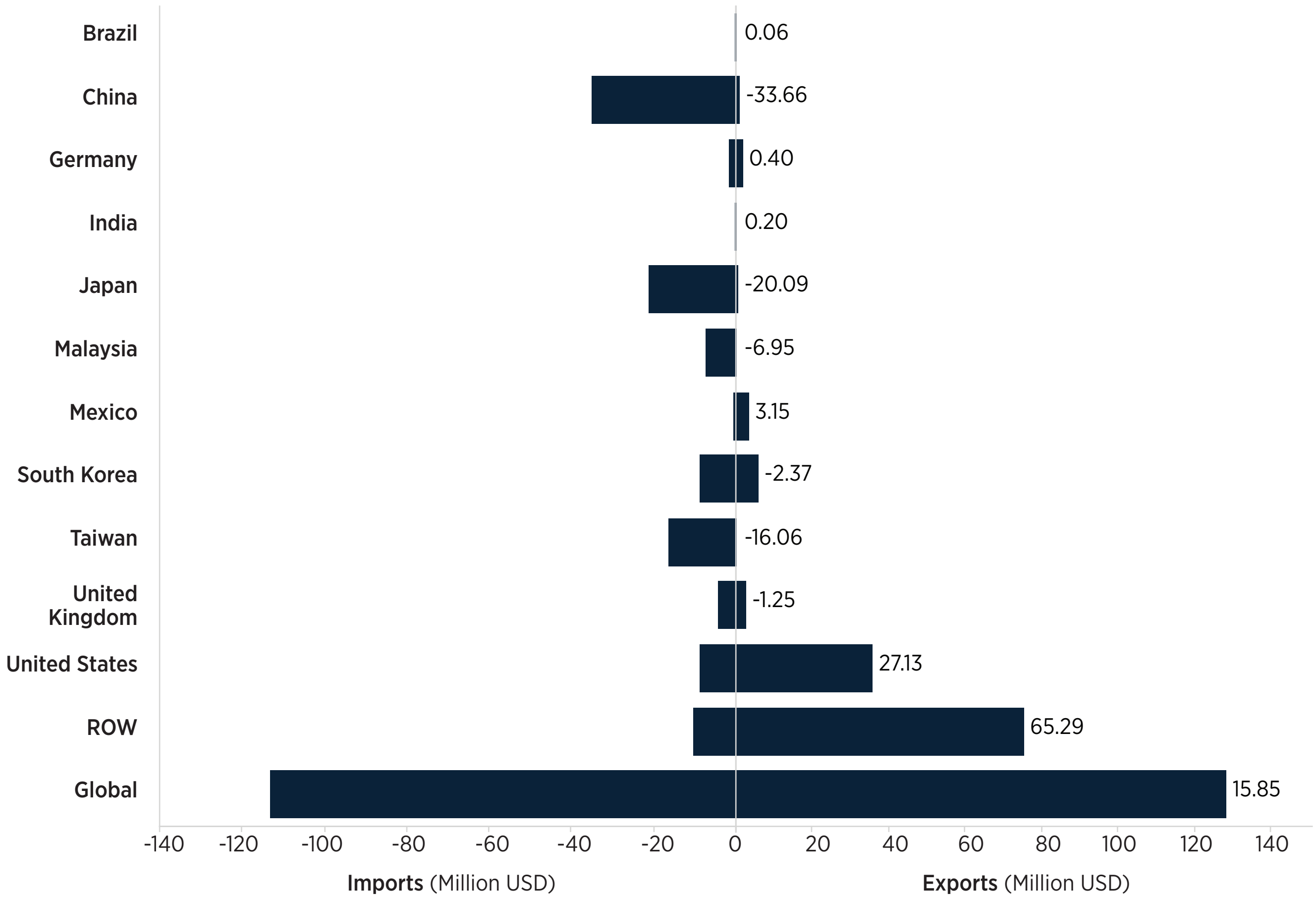


Figure 10-6. Canada's 2014 trade flows and balance of trade for LED packages. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

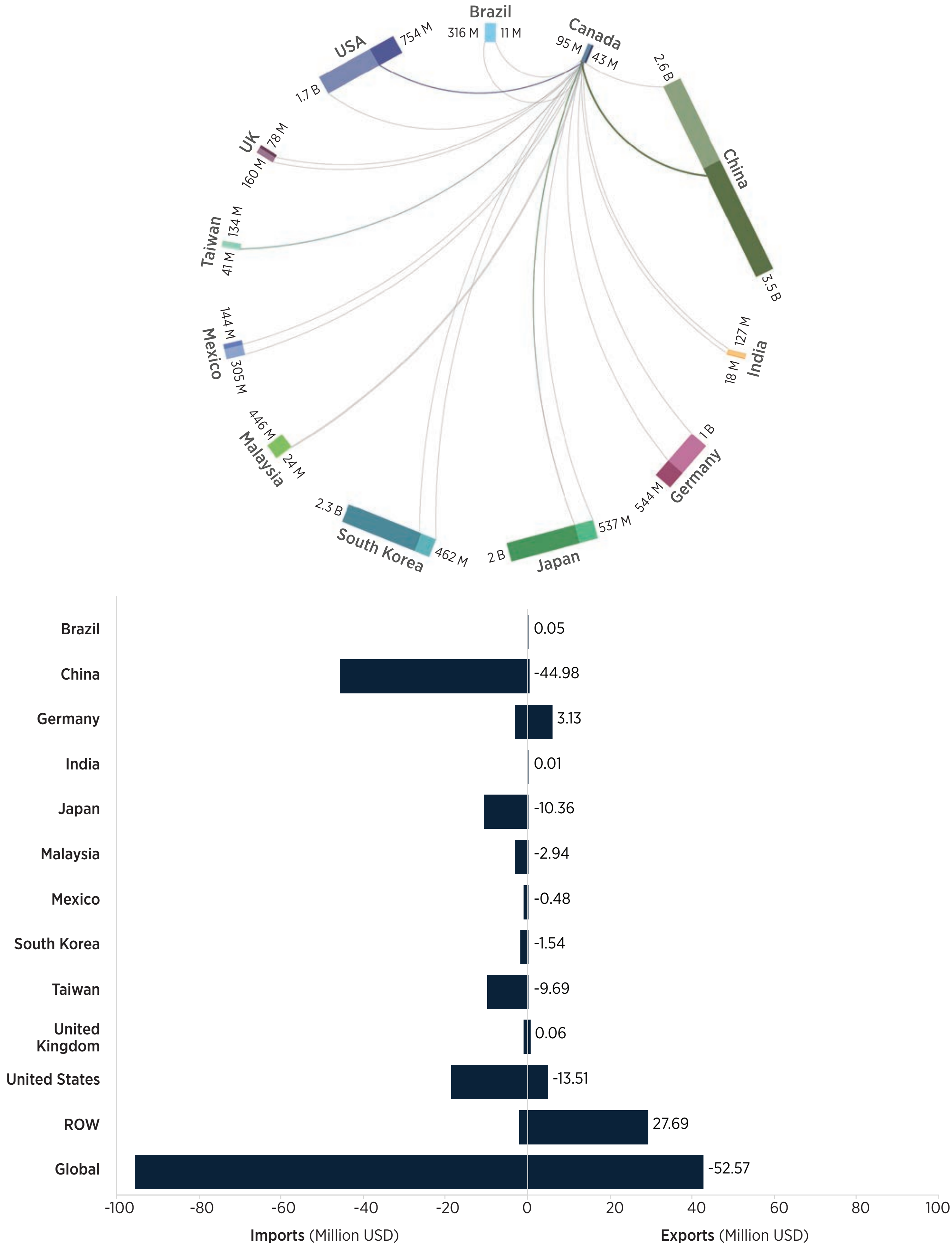


Figure 10-7. Canada's 2014 trade flows and balance of trade for Li-ion battery cells. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

11a | Mainland China & Hong Kong (China): Clean Energy Manufacturing Profile

China has the world's second largest economy, with a GDP of nearly 11 trillion USD in 2014. Rapid economic expansion in the past decades has led to increasing energy demand. Generation capacity is 1,360 GW as of 2014, and clean energy investment is growing. China had a cumulative 28 GW of PV and 115 GW of wind generation installed in 2014 (IRENA 2015a). Chinese manufacturing of clean energy technologies is expanding to meet both local and global demand. A range of policies have boosted the domestic clean energy industry in order to establish China as a competitive manufacturing base for clean energy technology, support economic development, and achieve its environmental goals.

Key Findings

- Due to the scale of China's industry and economy, in 2014, value added (in dollar value) was higher than all other economies included in this study. Manufacturing of wind turbine components, PV modules, LED packages, and LDV Li-ion batteries contributed a total of 38.8 billion USD in value added to China's economy. Value added retained was about 53% in China, just below the average of 55% for the economies included in this analysis. Factors contributing to China's value added rate include government subsidies to industries, importing inputs used in production, lower wages, and lower property-type income such as profits.
- China produces 45% of the world's wind turbines, and 70% of the world's PV modules, a significant portion of which are consumed domestically. Nonetheless, China's clean energy manufacturing capacity is underutilized, in part because job development pressures at the federal, provincial, and municipal levels led to easy access to capital and capacity expansion.
- For the four technologies considered, in 2014, exports totaled 21.4 billion USD and imports totaled 13.7 billion USD, leaving China with an overall positive balance of trade (7.7 billion USD).[27] The top trading partners with China were the United States, Japan, South Korea, and Taiwan. Among clean energy manufacturing products, China exported the most PV modules and cells while importing the most LEDs.

Economy

- GDP (nominal USD, 2014): 10,983 billion (World Bank 2016)
- Economy-wide value added contribution: 31% of all economic activity (gross output) in 2014
- Import contribution: 6% of gross output, 2014 (World Bank 2016)
- Four-year economic growth rate (2011-2014): 8.5% (World Bank 2016)
- Manufacturing, value added (% of GDP 2013) : 30 (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.6

Trade

- Total imports (USD, 2014): 1,958 billion (WITS)
- Total exports (USD, 2014): 2,342 billion (WITS)
- Main trading partners (2015): United States, Hong Kong, Japan, South Korea (exports) (CIA 2016)
- Main trading partners: South Korea, United States, Japan, Germany, Australia (imports) (CIA 2016)

Energy Sector

- Total Installed generation capacity: 1,360 GW (China Electricity Council 2015)
- Renewable share (excluding large hydro): 18% (China Electricity Council 2015; IRENA 2015)
- Total Investment in Clean Energy (USD, 2014): 243.2 billion (BNEF 2016)

RE and EE Targets

- Non-fossil fuels share of primary energy consumption 15% by 2020
- 16% reduction in energy intensity between 2010–2015

27. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

Value Added: Clean Energy Manufacturing Impact on the Economy

Due to the scale of China's industry and economy, value added in dollar value is higher than all other economies included in this study. As illustrated in Figure 11-1, manufacturing of wind turbine components, PV modules, LED packages, and LDV Li-ion batteries added a total of 38.8 billion USD in value added (14.6 billion USD direct, 24.2 billion USD indirect) to China's economy in 2014. Across the supply chain, the highest total value added came from wind turbine components (19.1 billion USD), PV modules (10.8 billion USD), and PV cells (4.9 billion USD).

In China, all of the clean energy technologies considered here generate more indirect value added than direct value added for all links in the supply chain except for polysilicon manufacturing. Overall about 40% of value added is direct, coming from the clean energy manufacturers themselves; and the remaining 60% comes from industries that support clean energy manufacturers or supply inputs.

Combined, for the four clean energy technologies included in this analysis, direct value added retained is about 20% below the average of 25% for the economies included in this analysis. This varies across the clean energy technologies considered: 15% for LED packages and Li-ion batteries, 16% for c-Si PV, and 26% for wind components.

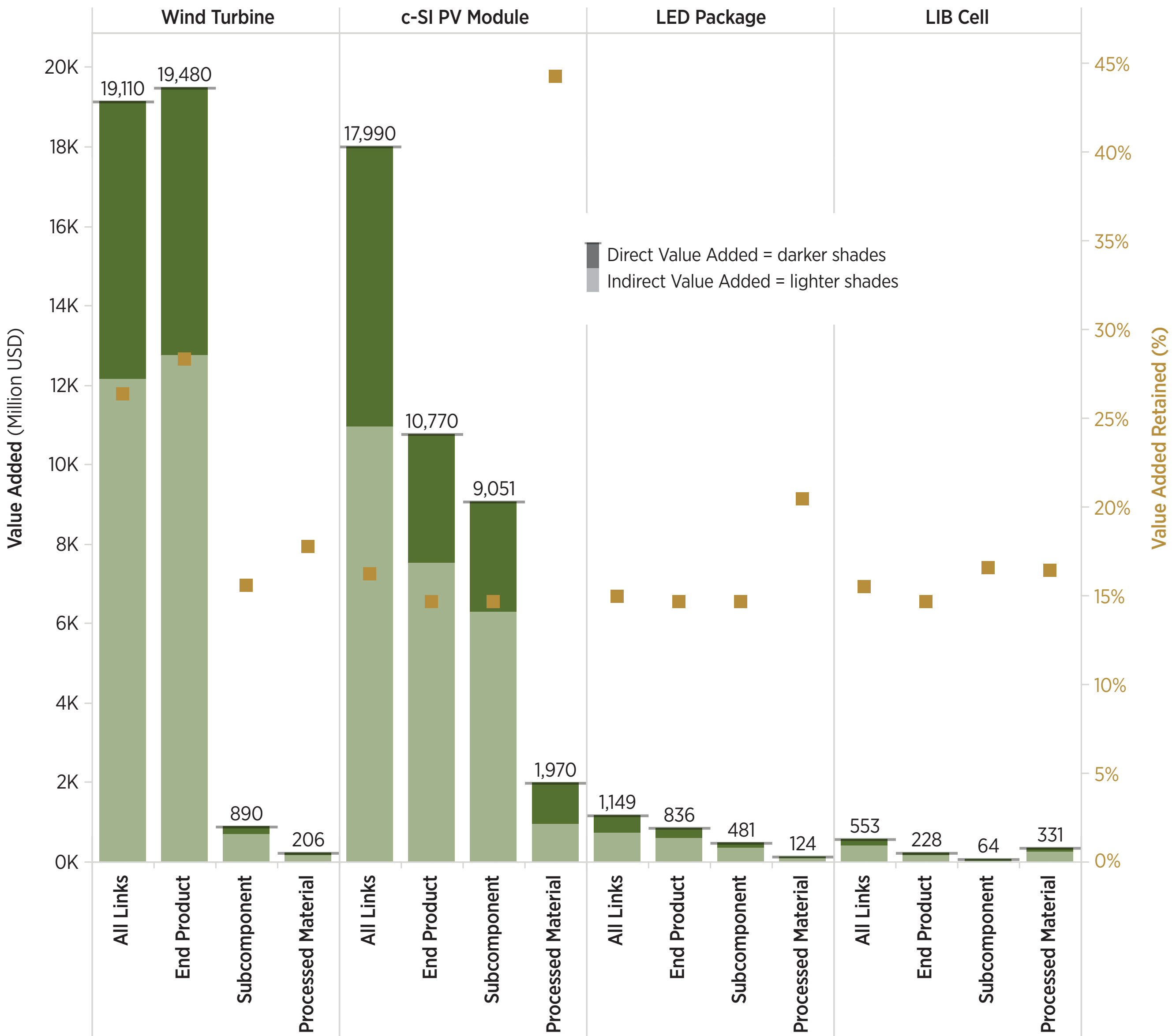


Figure 11-1. China's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

China's direct value added across all industries as a proportion of its gross output is 53%, or seventh of the economies considered.

China's domestic supply chains are among the most developed of the economies considered. China is highest among the 12 economies in both domestic inputs as a share of gross outputs and in domestic intermediate inputs as a share of total intermediate inputs. The portion of revenue that leaves the economy to pay for imported inputs is 10%, compared to the 12-economy average of 11%. Value added retained is 31%, smaller than the 46% 12-economy average.

Manufacturing Landscape: Demand, Manufacturing Capacity and Production

China is the world's largest manufacturer, accounting for nearly a quarter of global value added in this sector (The Economist 2015). In terms of GDP, China's manufacturing sector contributed 28% to its national economy in 2014, equivalent to 3.1 trillion USD (World Bank 2016a).

To push renewable energy technology development and bolster manufacturing, China has implemented R&D investment, rebates, production-based incentives, targeted tax reductions, and investment incentives. Provincial and municipal governments have also provided support in various forms, including tax holidays, access

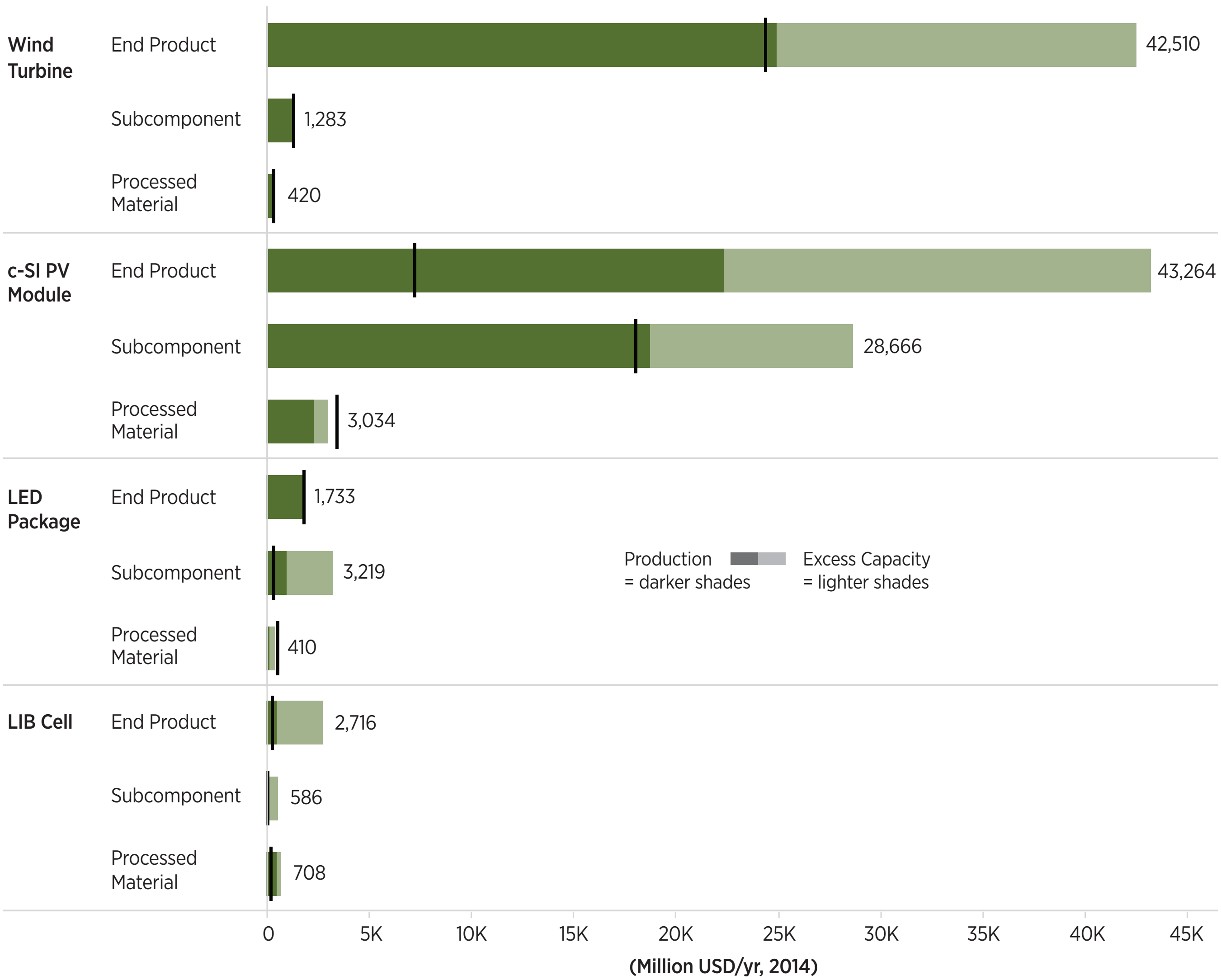


Figure 11-2. China demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies (for LED packages, assumed production equal to demand due to lack of demand data), 2014. See methodology report for data quality discussion.

to low-cost energy and land, loan interest refunds, and various investment grants. (Lewis 2013.) These policies have incentivized investment into the clean energy sector and contributed to its growth.

A number of policies, most notably a 70% domestic content mandate and requirement for majority Chinese ownership of wind projects to qualify for the Clean Development Mechanism under the Kyoto Protocol, enabled the establishment of a domestic Chinese wind power manufacturing supply chain. Similarly, China has provided nationally supported tax, investment incentives, and R&D support targeting the development of advanced energy storage technologies and manufacturing (including Li-ion batteries and related materials and components). In 2009, local governments began issuing fiscal subsidies for Metal-Organic Chemical Vapor Deposition (MOCVD) reactors, which encouraged development of LED wafer plants in China. The national government mandated that local governments stop issuing such subsidies in 2014. While these policies have helped China's clean energy manufacturing sector grow rapidly, they have also led to oversupply in wind, solar and LED manufacturing capacity, as well as other industries, in China and globally.

As markets have matured and other low-cost economies have developed competing manufacturing assets, China is taking steps to upgrade its industry through the "Made in China 2025" initiative. The goal is to improve the efficiency and integration of Chinese industry so that it can occupy the highest parts of global production chains and compete with advanced industrialized economies. The plan identifies the goal of raising domestic content of core components and materials to 40% by 2020 and 70% by 2025. While the goal is to upgrade industry overall, the plan highlights ten priority sectors, including new-energy vehicles and equipment and power equipment. (Kennedy 2015.)

In 2014, China was the global leader in wind turbine component and c-Si PV module manufacturing, and hosted significant portions of the LED package and LDV Li-ion battery manufacturing supply chains. Figure 11-2 shows China's 2014 manufacturing capacity, production, and demand for these four technologies.

Across the wind turbine supply chain, China hosted the largest shares of manufacturing capacity for nacelles, blades, and towers, and generators with 51%, 48%, 40%, and 49% of the global total, respectively. For PV modules, China hosted the largest shares of manufacturing capacity across the supply chain, with 74% of the global manufacturing capacity for PV modules, 67% for PV cells, 76% for PV wafers, and 44% for polysilicon. China's LED chip and sapphire substrate manufacturing capacities were the largest and second largest globally (46% and 29%, respectively), while its LED package capacity (11% of the global total) ranked fifth. China's share of LDV Li-ion cell, cathode, anode, and separator manufacturing capacities were the largest globally (32%, 48%, 62%, and 59%, respectively) and its electrolyte capacity share (25%) was the second largest in the world in 2014.

Relative to other producer nations within each technology sector, Chinese capacity utilization rates were generally reflective of global averages in 2014. Notable exceptions include LDV Li-ion cell and separator capacity utilizations, which were particularly low at 17% and 15%, respectively. At 52%, China's PV module utilization was also slightly below the global average of 55%.

From the demand side:

- China was the largest market for both wind turbine components and PV modules, demanding 23,200 MW of wind turbines and 10,100 MW of PV modules in 2014.
- China's LED package demand of 18.6 billion packages made it the fifth largest market globally.
- China's LDV Li-ion cell demand of 600 MWh made it the fourth largest cell market in 2014.

Trade Landscape: Balance of Trade and Trade Flows

According to the World Trade Organization (WTO), China has become the world's largest trader (excluding trade within the European Union), with exports of 2.2 trillion USD and imports of 1.8 trillion USD in 2014. Manufactured products are the dominant component of China's exports, accounting for over 94% of the total (in 2013) (WTO 2014).

Historically, China's policies for the clean energy industry have been designed to both protect domestic manufacturers from foreign competition, such as the case of wind, and to promote export, such as in the PV industry. Some of these policies have been subject to investigation in a number of anti-dumping and anti-subsidy disputes between China and the United States and the European Union. [ICTSD 2013a] Some trade tariffs imposed over the past few years include: U.S. and European Union anti-dumping and anti-subsidy duties on Chinese and Taiwanese cells and modules (USITA 2012; European Commission 2015), Chinese anti-dumping duties on U.S. solar-grade polysilicon (ICTSD 2013b), and U.S. duties on wind towers from China (ICTSD 2012).

To foster greater trade and address significant overcapacity in its steel and construction sectors, China's "One Belt, One Road" plan, announced in 2013, aims to build infrastructure to support trade into Europe and Asia (State Council 2015).

The balance of trade and trade flows for the supply chain links for which trade data are available are presented in Figures 11-3 through 11-7. China is a significant exporter of clean energy components with 21.4 billion USD in exports in 2014 and a positive balance of trade of 7.8 billion USD overall.[28]

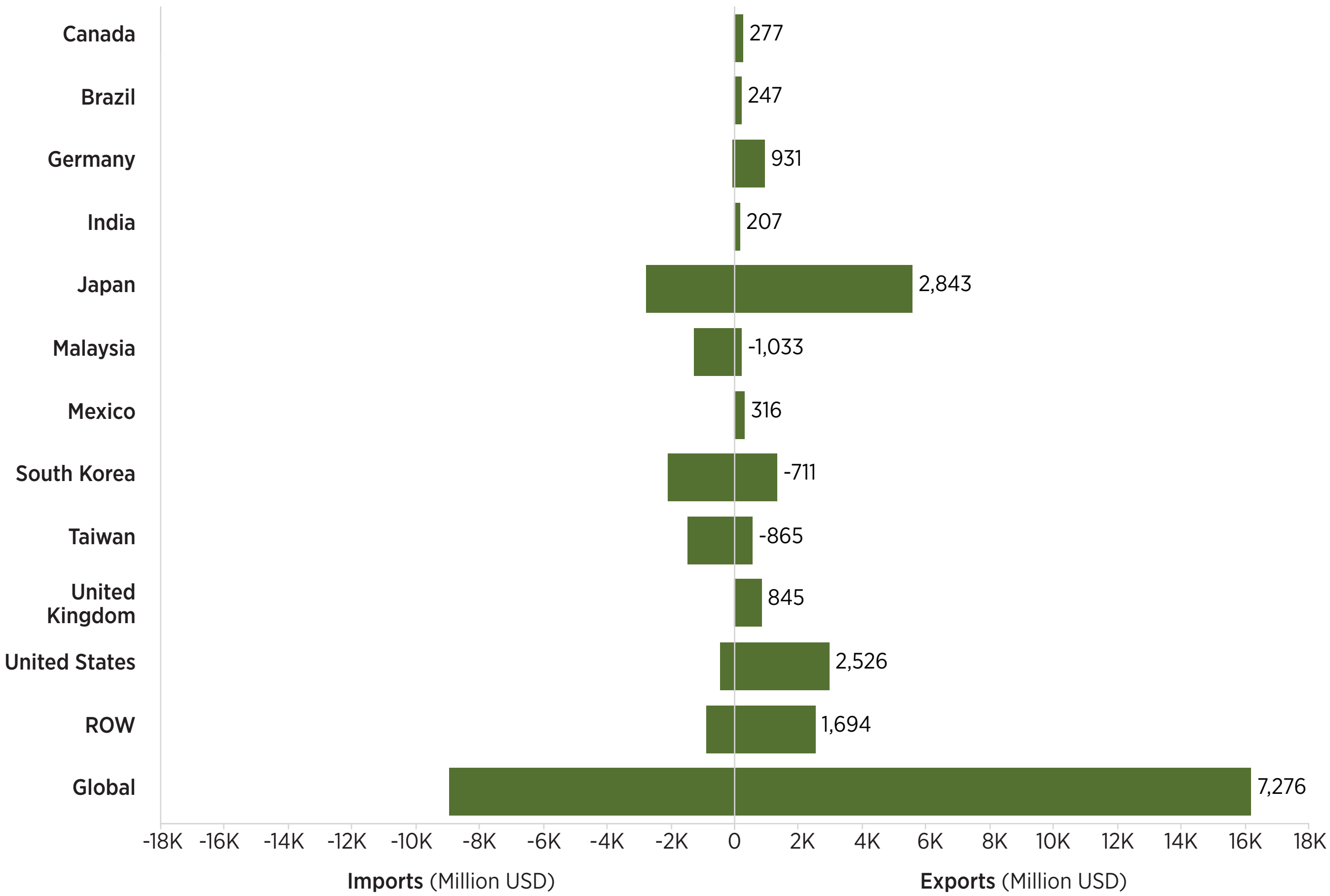


Figure 11-3. China's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

28. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

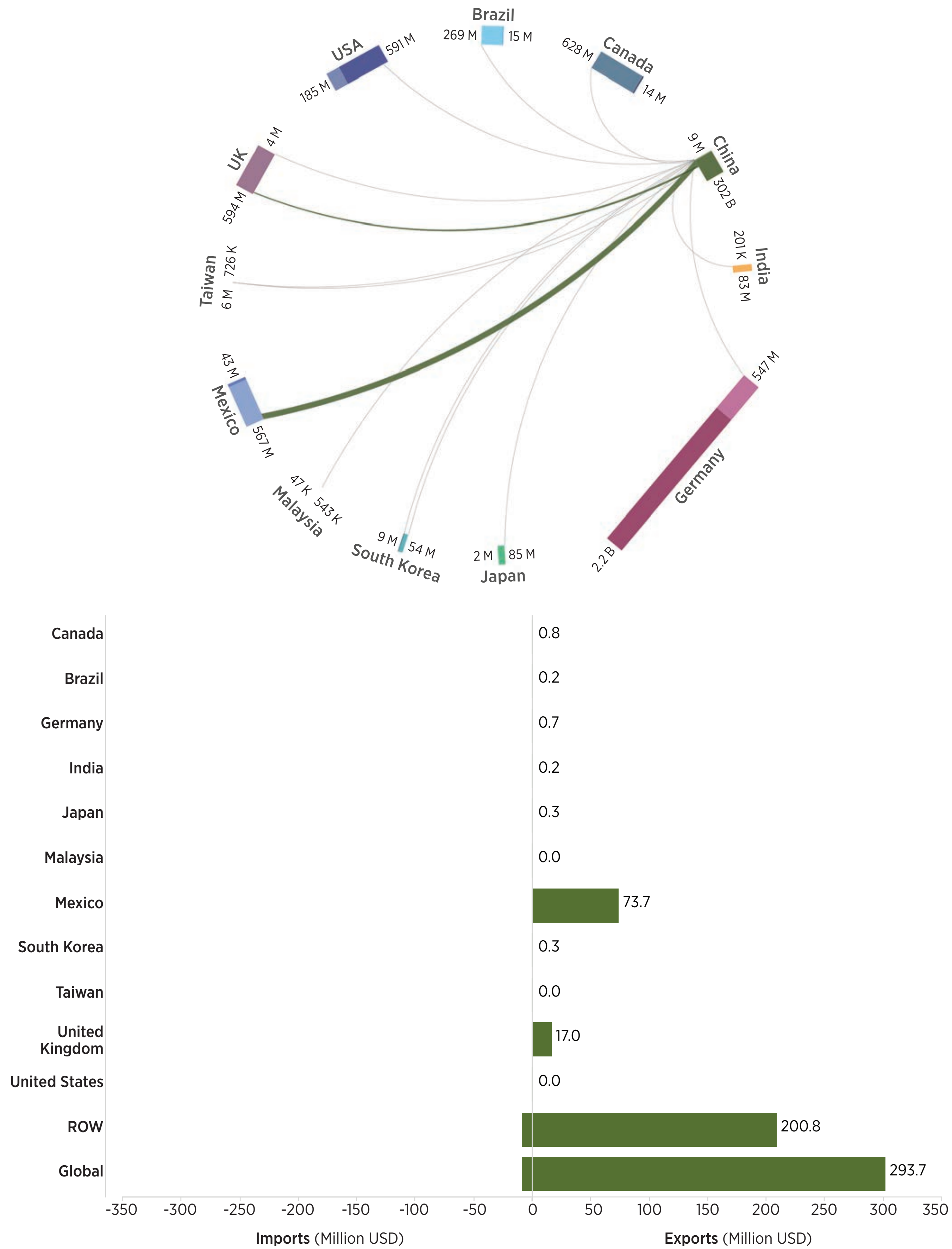


Figure 11-4. China's 2014 trade flows and balance of trade for wind turbine generator sets. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

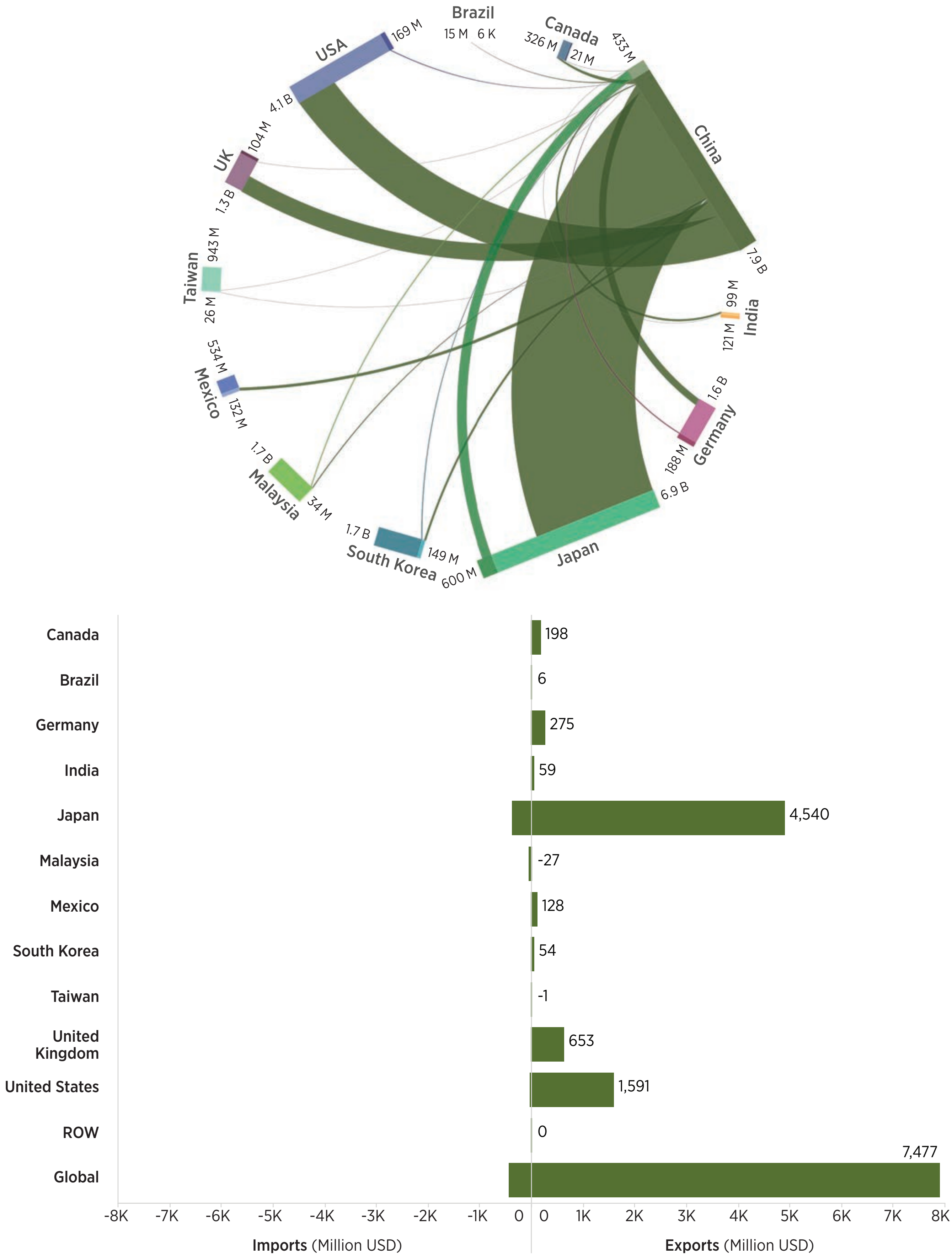


Figure 11-5. China's 2014 trade flows and balance of trade for PV modules. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

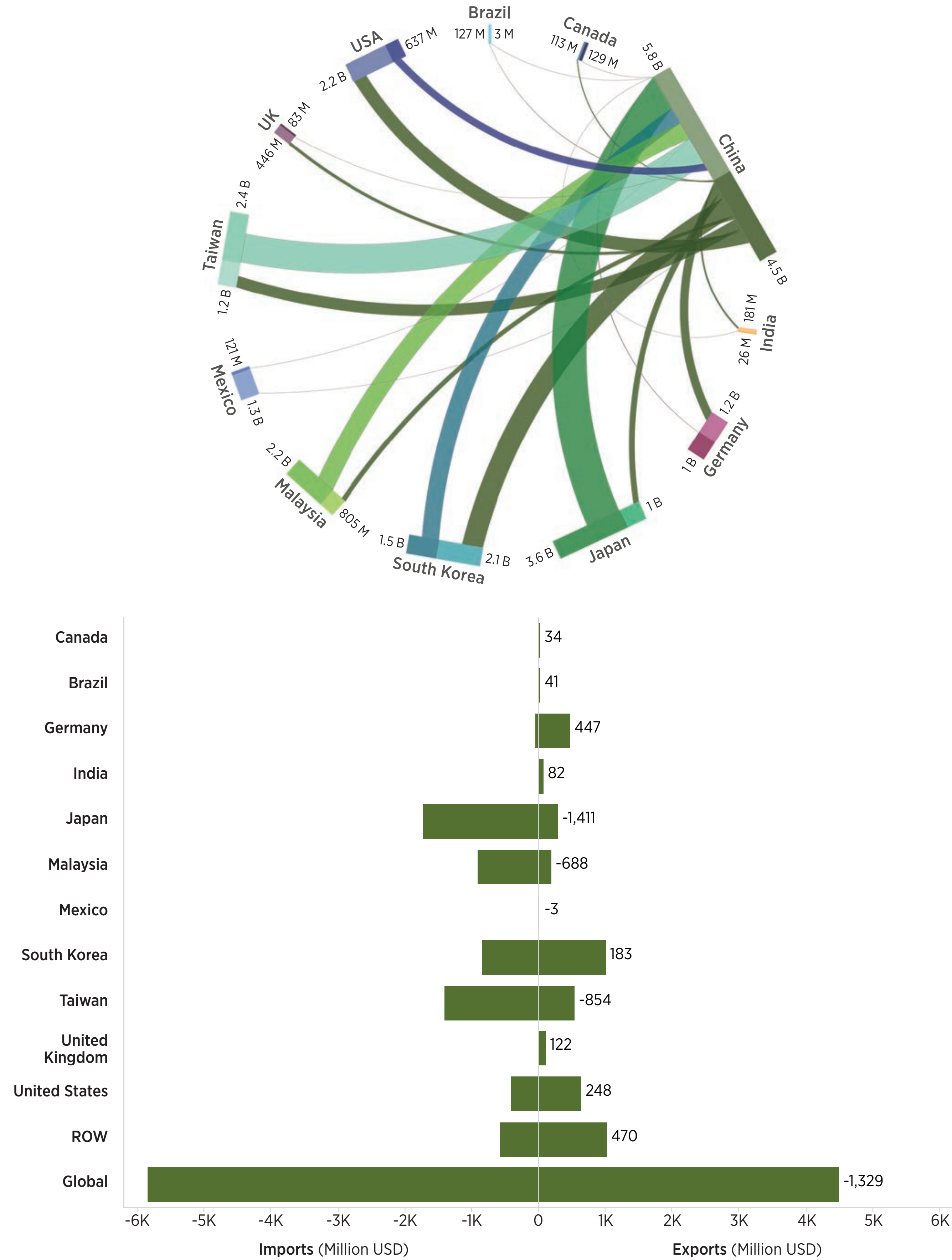


Figure 11-6. China's 2014 trade flows and balance of trade for LED packages. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

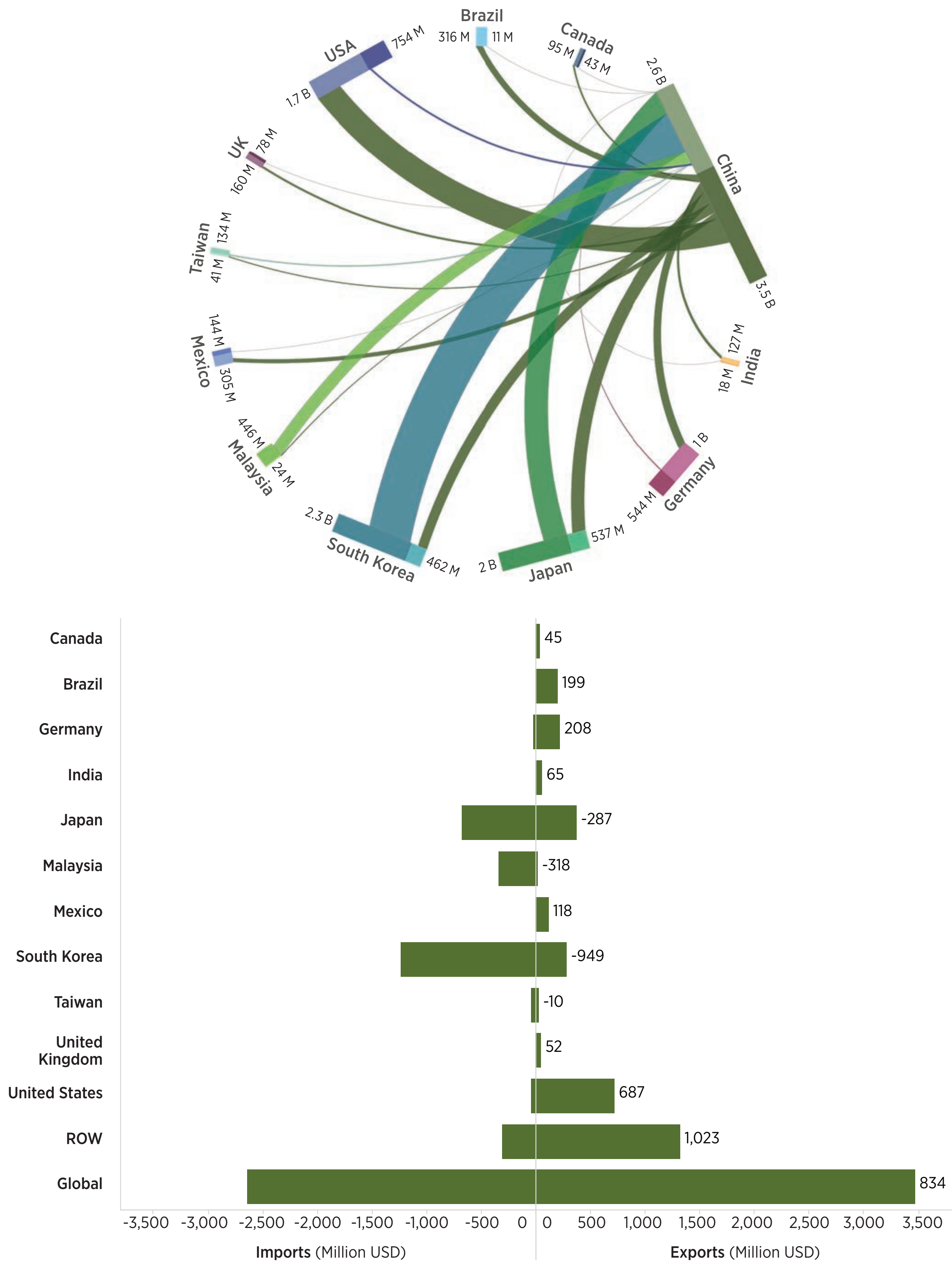


Figure 11-7. China's 2014 trade flows and balance of trade for Li-ion battery cells. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

11b | Republic of China (Taiwan): Clean Energy Manufacturing Profile

Taiwan's economy is the twenty-sixth largest in the world, with a GDP of 530 billion. In 2014, Taiwan had a cumulative 633 MW of wind power, and a 776 MW of solar out of 48.5 GW of total generating capacity (IRENA 2015a). Capacity is expected to grow to 8.7 GW of solar and 5.2 GW of wind (both on and off shore) by 2030. As a result, clean energy manufacturing (particularly of solar modules) has continued to expand to meet domestic and international demand for clean technologies.

Key Findings

- In 2014, manufacturing of PV modules, LED packages, and materials for LDV Li-ion battery cells supported 2.7 billion USD in direct and indirect value added in Taiwan. The highest levels of value added supported by clean energy manufacturing technologies were in c-Si PV, with 1.5 billion USD. This was followed by LEDs (1.5 billion USD), and LDV Li-ion battery production (9 million USD). Taiwan did not produce wind components.
- In 2014, Taiwan was a leader in PV cell and wafer manufacturing, second only to China, and the fourth-largest manufacturer of LDV Li-ion battery cathode materials.
- For the four technologies considered, in 2014, exports totaled 7.4 billion USD and imports totaled 2.5 billion USD, leaving Taiwan with an overall positive balance of trade (4.9 billion USD) in clean energy manufacturing products.[29] The top trading partners with Taiwan were China, Japan, and South Korea. Among clean energy products, Taiwan exported more PV cells and modules than any of the other selected clean energy technologies and imported more LEDs.

Value Added: Clean Energy Manufacturing Impact on the Economy

As illustrated in Figure 11-8, in 2014, 6.7 billion USD in revenue from manufacturing of PV modules, LED packages, and materials for LDV Li-ion battery cells manufacturing supported 2.7 billion USD of value added in Taiwan (1.7 billion in direct value added and 1.1 billion in indirect value added).

Across all components, direct value added was greater than or equal to indirect value added. The limited indirect effects show

Economy

- GDP: 523.6 billion USD (Statistics Bureau 2016)
- Direct value added contribution: 39% of gross output
- Import contribution: 20% of gross output
- Five-year GDP growth rate (2010–2014): 4.5% (Statistics Bureau 2016)
- Manufacturing Sector Contribution to GDP: 29.6% (Statistics Bureau 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.6[30]

Trade

- Total imports (USD, 2016 est): 249 billion (CIA 2016)
- Total exports (USD, 2016 est): 315 billion (CIA 2016)
- Main trading partners: China, Hong Kong (exports)
- Main trading partners: Japan, China (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 48.5 GW (Bureau of Energy 2016)
- Renewable share (excluding large hydro): 4.1% (Bureau of Energy 2016)
- Total Investment in Clean Energy (USD, 2014): 296 million (BNEF 2016)

RE and EE Targets

- 17 GW of installed renewable capacity by 2030
- Energy intensity 50% lower than 2005 levels (Bureau of Energy 2013)

30. Taiwan's PPP conversion factor assumed to be equal to China's

29. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

that to the economy of Taiwan, clean energy manufacturers themselves are the most significant when compared to their greater supply chains.

Taiwan's direct value added retained from clean energy manufacturing was 25%, equal to the 12-economy average. Clean energy manufacturers in Taiwan supported 25%, 25%, and 22%, respectively, in direct value added as a portion of revenue, for manufacture of LED packages, c-Si PV modules, and Li-ion battery cells.[31]

Total direct and indirect value added retained in Taiwan was below the average for clean energy manufacturers in 2014 (Figure 11-8). It was 41% for all technologies, compared to the 55% average among all economies in this report. This was also true for each technology. Solar PV was 40% (45% average), LEDs was 41% (47% average), and batteries was 47% (68% average). The average direct and below average indirect value added percentages of output in Taiwan are indicative of limited domestic supply chains across clean energy manufacturing industries as well as the economy as a whole.

The percentage of value added across all industries that Taiwan retains as a portion of revenue economy-wide

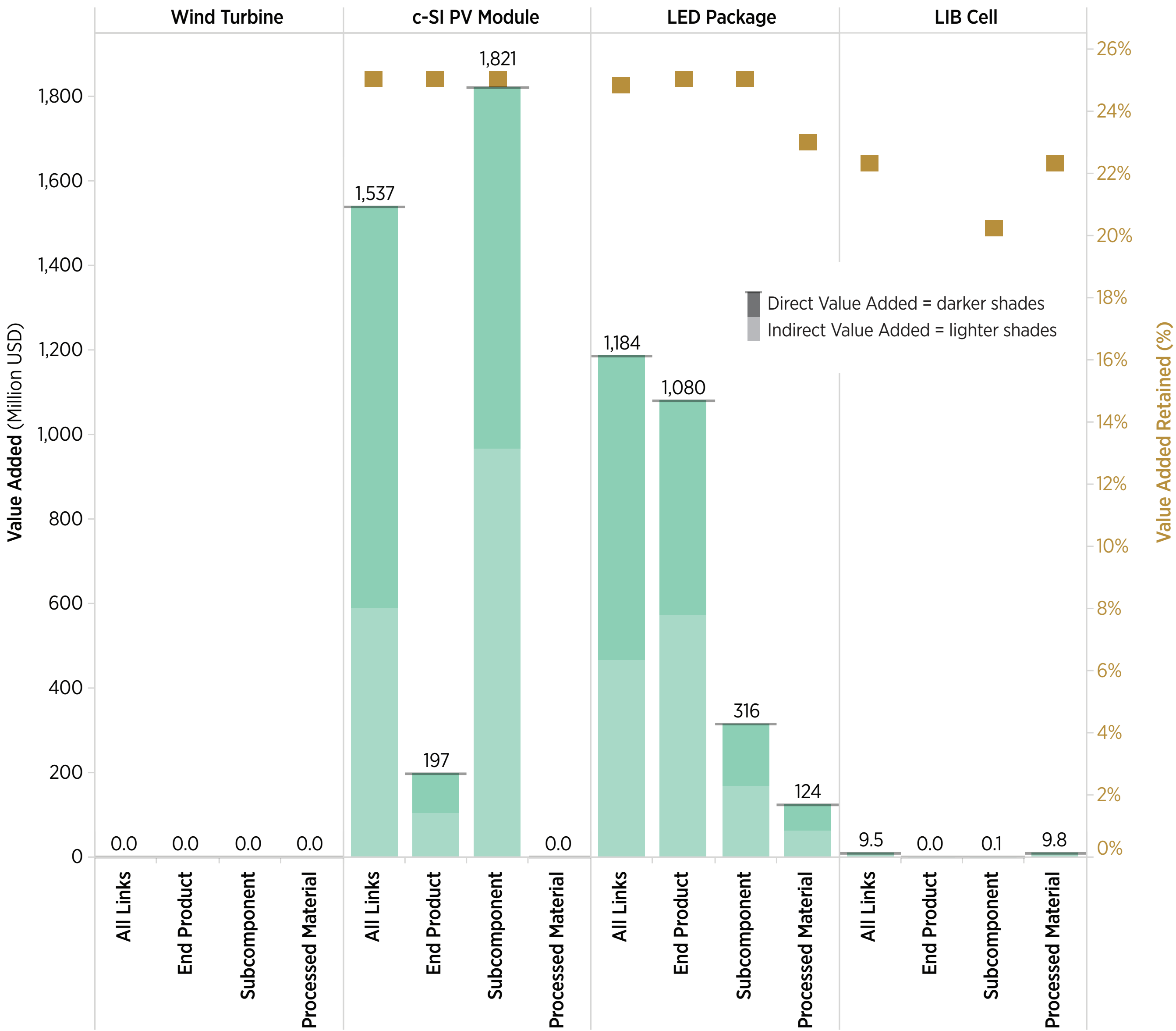


Figure 11-8. Taiwan's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

31. OECD STAN (2015)

is 39%, the third lowest among the economies included in this report. Only Malaysia (34%) and China (31%) were lower. Taiwan is low compared to other economies because the economy in Taiwan is smaller and supply chains are less developed. Taiwan imports 20% of inputs used in production compared to the 12-economy average of 11%. Lower wages, property-type income (including profits), and taxes also contribute to lower value added. Economic growth and the domestic development of supply chains, however, could increase value added.

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

Manufacturing sector has long been one of Taiwan's stronger economic sectors. Manufactured goods make up 29.6% of GDP, equivalent to 155 billion USD in 2014.

In 2014, Taiwan hosted notable PV cell, PV wafer, and Li-ion battery cathode materials manufacturing; Taiwan was also home to an established manufacturing base for LED packages, chips, and sapphire substrate. Taiwan did not host any significant wind turbine or component manufacturing capacity in 2014. Figure 11-9 shows Taiwan's 2014 manufacturing capacity, production, and demand for the four technologies included in this analysis.

In 2014, Taiwan hosted 9,500 MW (14% share of the global total) of PV cell manufacturing capacity, and 5,700 MW (8% share) of wafer manufacturing capacity. These made Taiwan the second largest producer of both cells and wafers in the world, trailing only China. Taiwan was also home to 1,600 MW (2% share) of module and 1,400 MW (2% share) of polysilicon manufacturing capacity. In 2014,

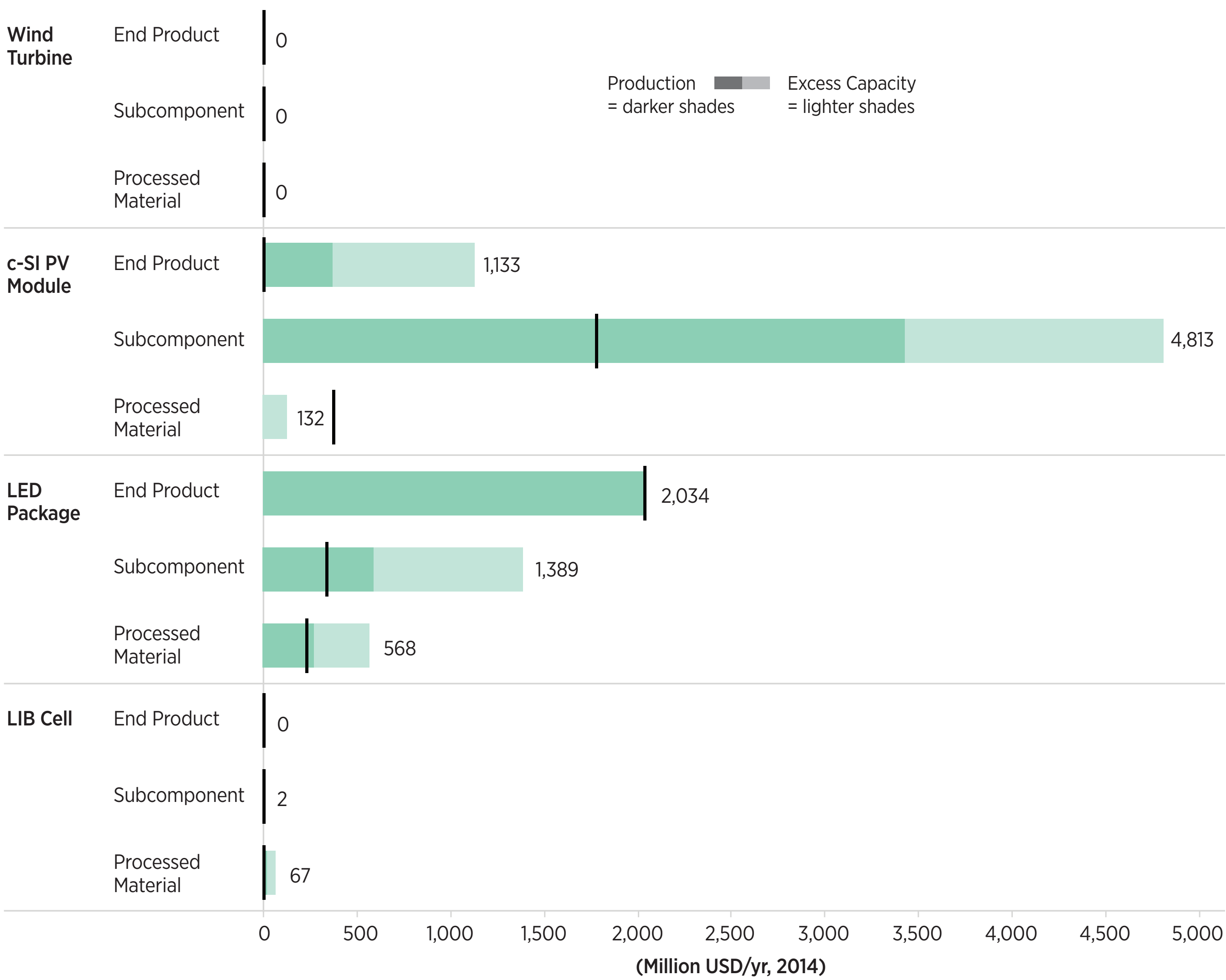


Figure 11-9. Taiwan's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies (for LED packages, assumed production equal to demand due to lack of demand data), 2014. See methodology report for data quality discussion.

the annual manufacturing capacity for LED packages, chips, and sapphire substrate totaled 21.9 billion packages (13% share), 31.3 billion packages (20% share), and 140.6 billion packages (40% share), respectively. In 2014, Taiwan was home to a material amount of LDV Li-ion cathode manufacturing, totaling 1,200 MWh (7% of the global total) of annual capacity. Taiwan also hosted a minor amount of automobile Li-ion battery separator manufacturing, totaling 100 MWh (<1% of the global total) of annual capacity.

Taiwan's PV module manufacturers achieved an average utilization rate of 33%, below the global average of 55%. However, Taiwanese cell manufacturers' average utilization was 71%, well above the global average of 63%.

On the demand side:

- Taiwan did not have any appreciable domestic market demand for wind turbine components, PV modules, or LDV Li-ion cells in 2014.
- In 2014, demand for LED packages in Taiwan was 21.9 billion packages, or about 13% of the global total. This demand made Taiwan the fourth-largest single economy market for LED packages in the world.

Trade Landscape: Balance of Trade and Trade Flows

Taiwan has been a leader in exports of electronics including personal computers and other consumer products. Much of Taiwan's exports are end products; components for the end products come primarily from China, Japan, and Korea (CIA 2016). Taiwan enjoys a privileged trading position with China. Recently, as China's domestic manufacturers have gained sophistication and higher skilled workers, demand for Taiwan's goods has diminished.

In Figures 11-10 through 11-14, we show the balance of trade and trade flows for the supply chain links for which trade data are available. Taiwan is a net exporter of PV modules, LED packages, and Li-ion battery cells and a net importer of a small amount of wind generator sets.

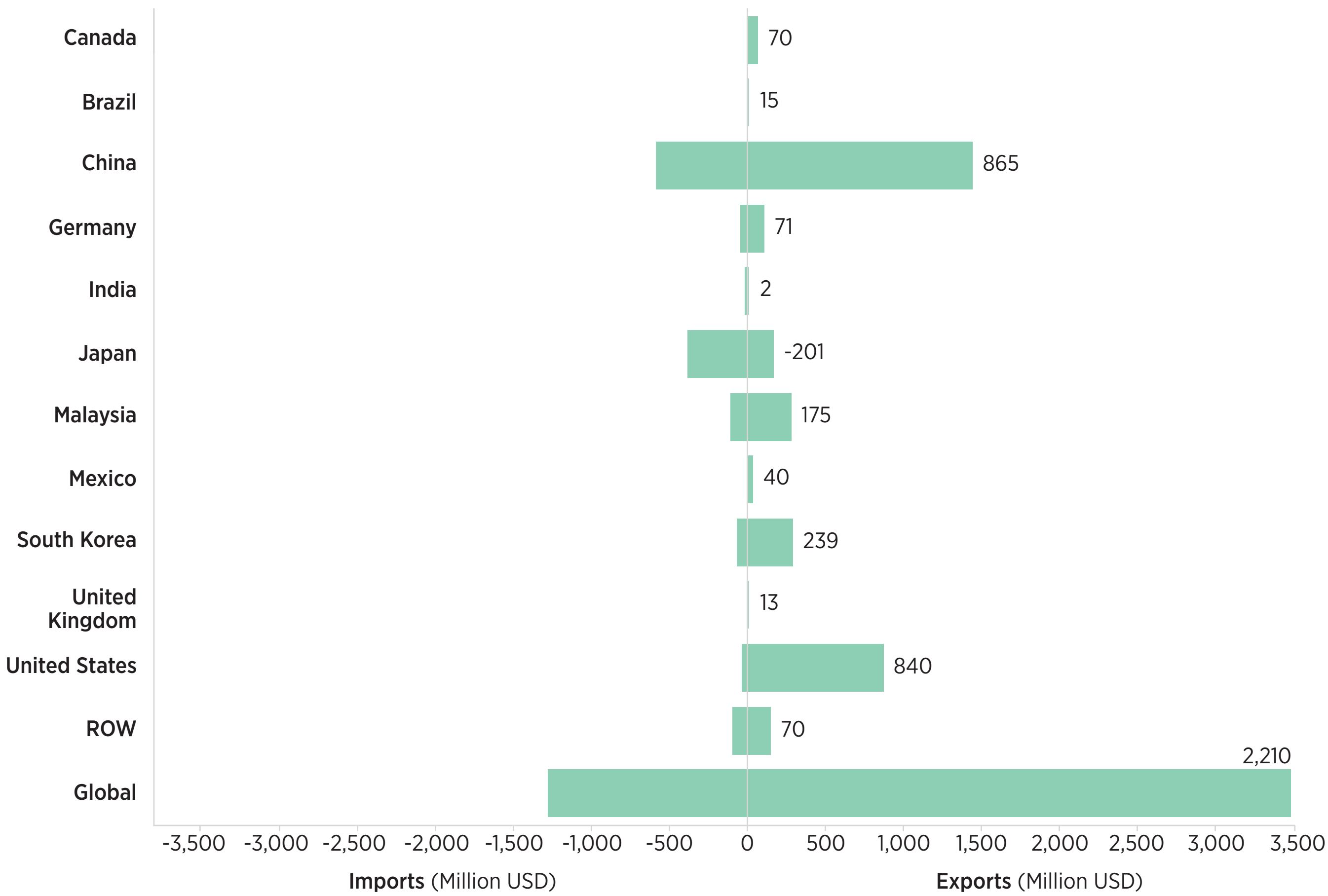
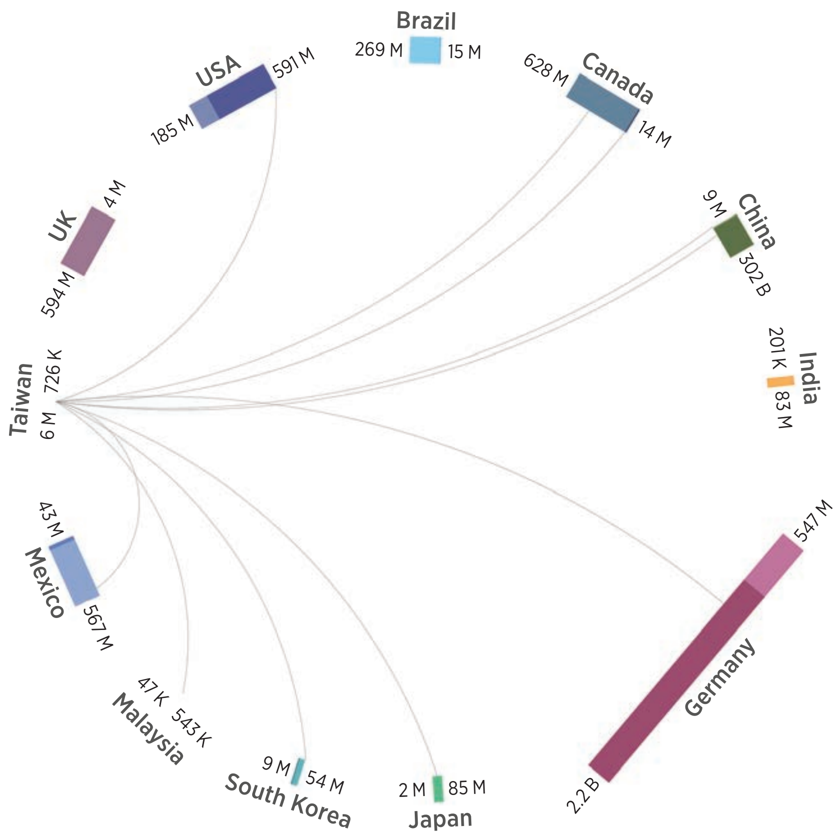


Figure 11-10. Taiwan's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.



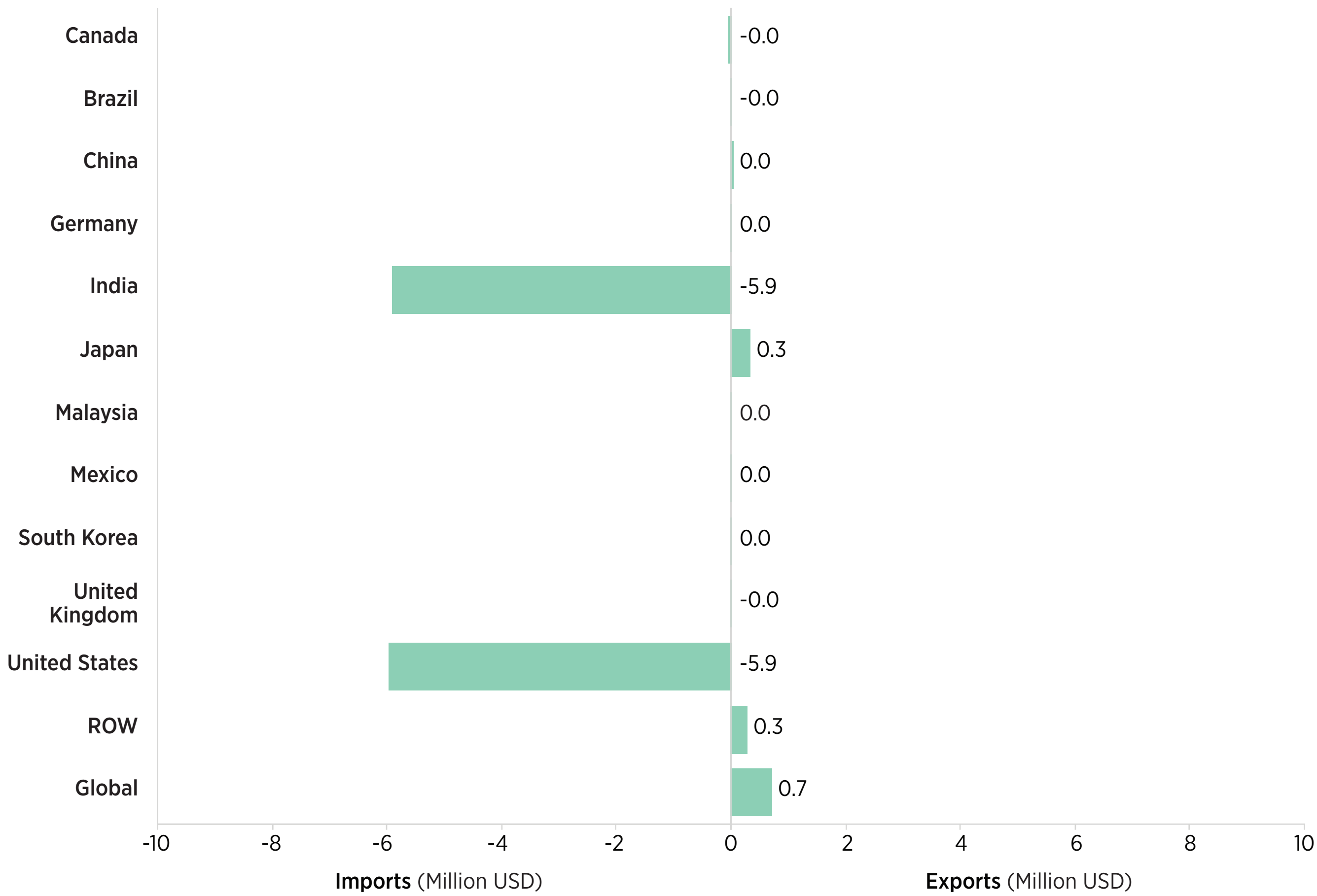


Figure 11-11. Trade between Taiwan and key partners in wind turbine generator sets, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

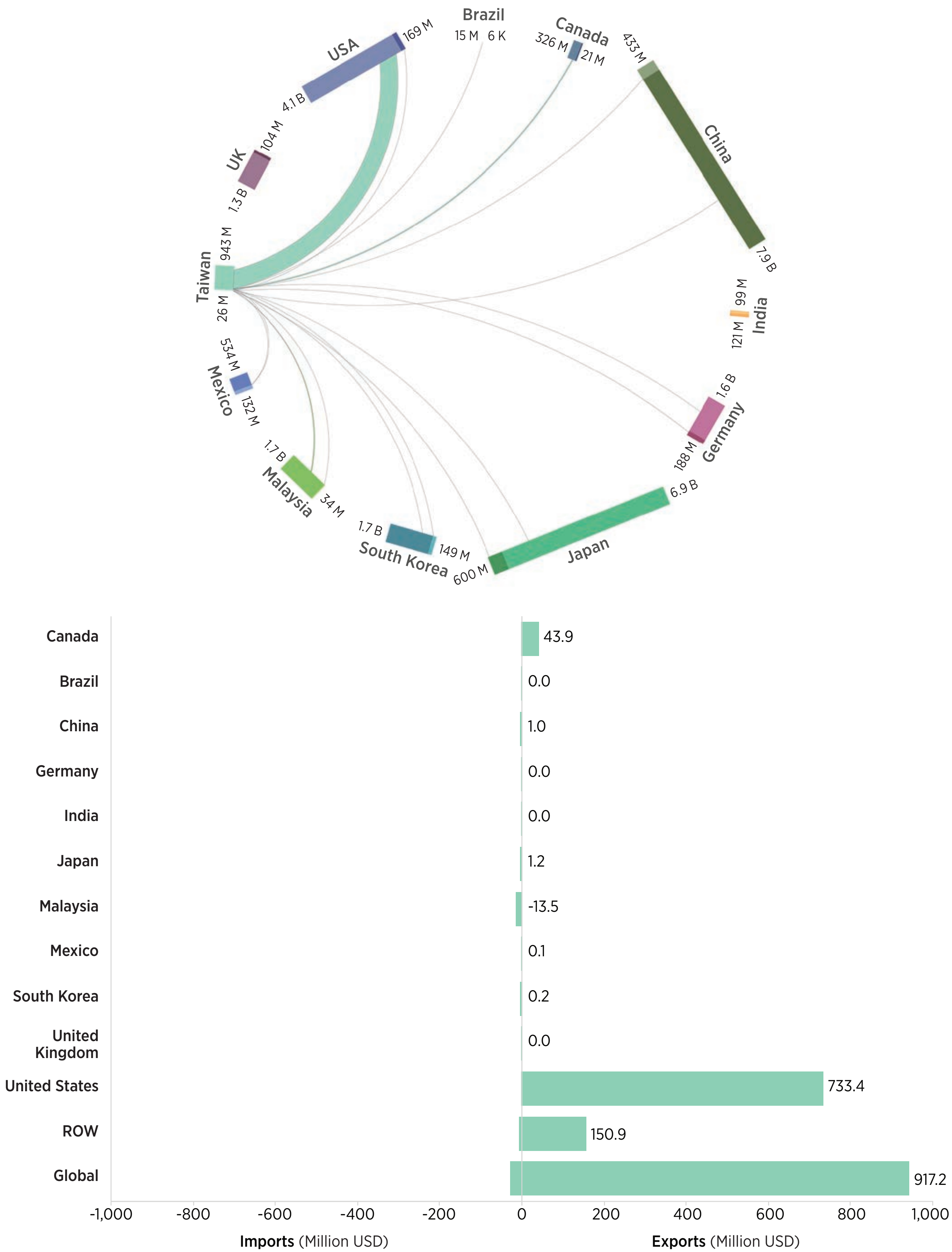


Figure 11-12. Trade between Taiwan and key partners in c-SI PV modules, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

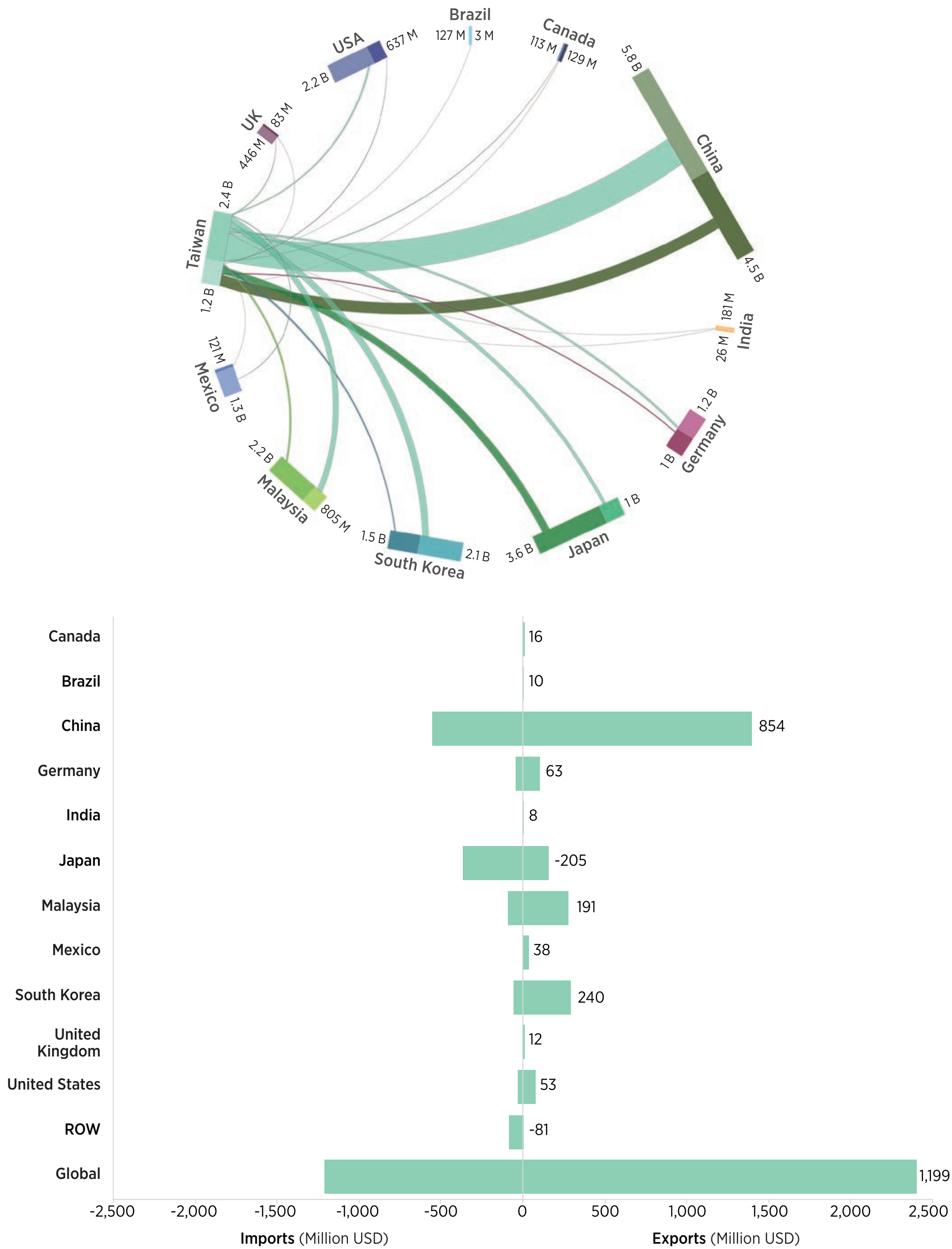
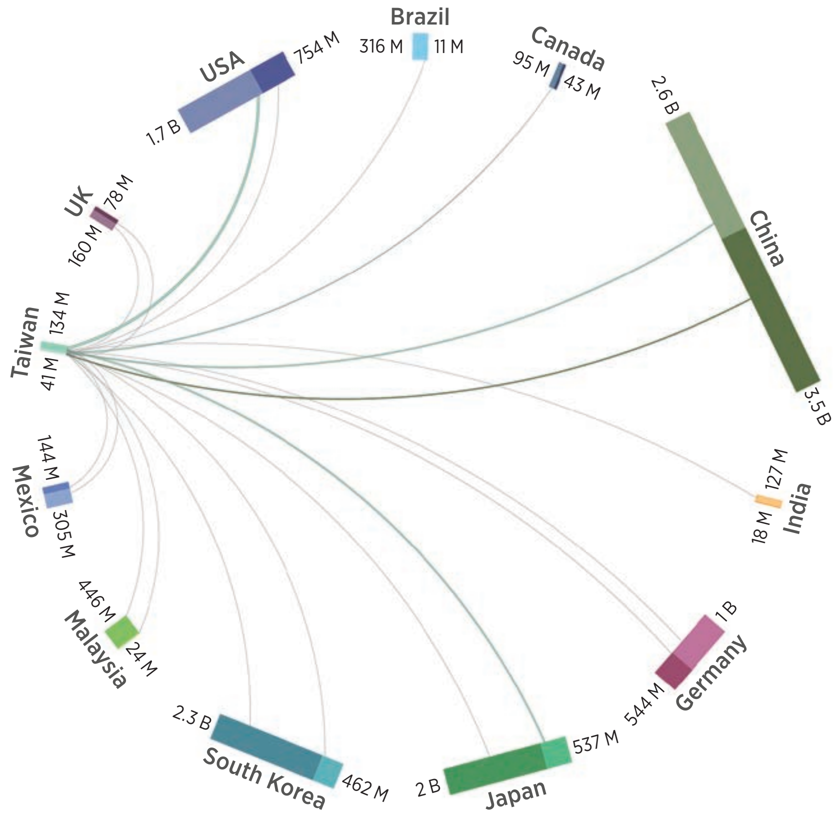


Figure 11-13. Trade between Taiwan and key partners in LED packages, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



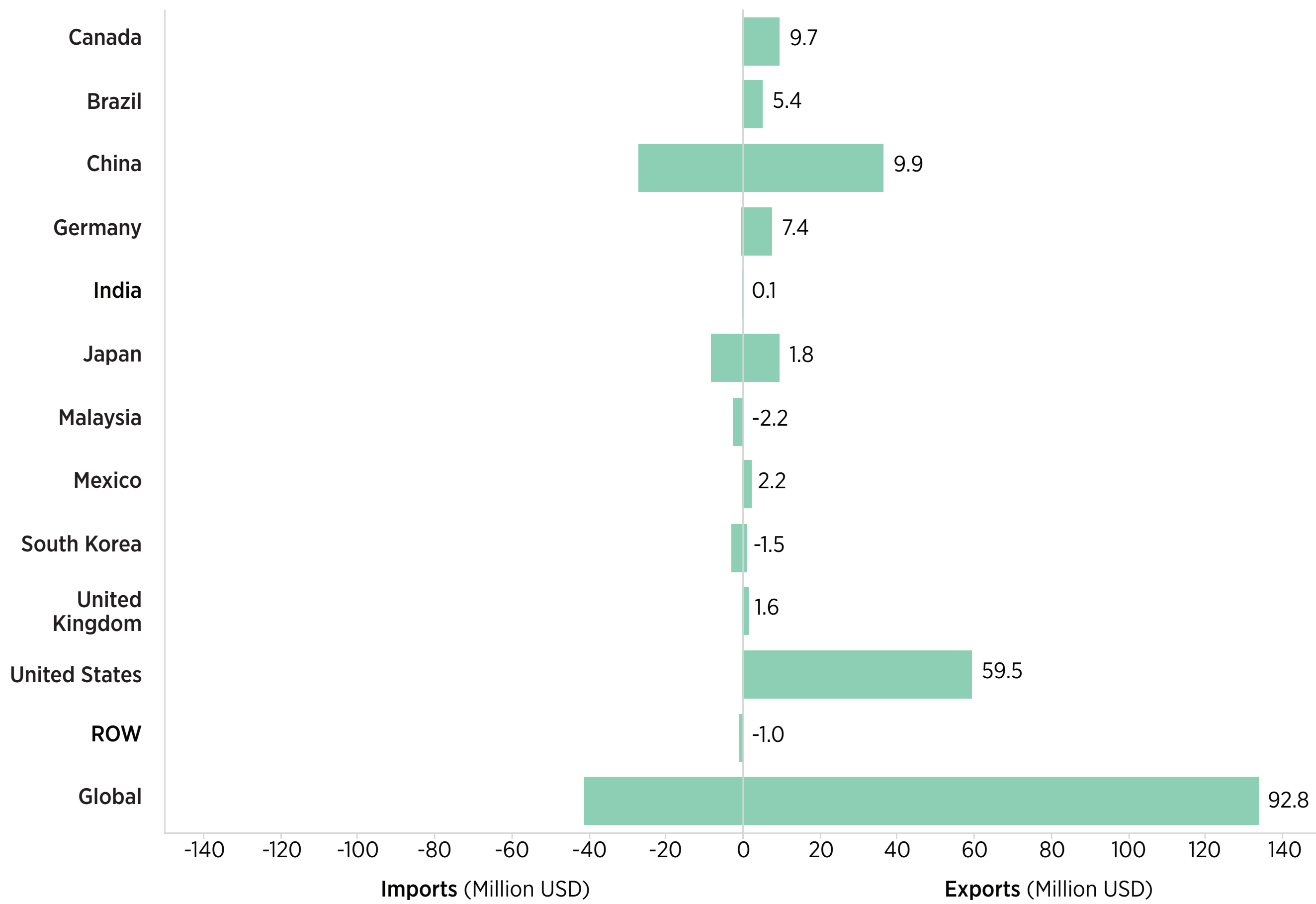


Figure 11-14. Trade between Taiwan and key partners in Li-ion cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

12 | Germany: Clean Energy Manufacturing Profile

Germany is the fourth largest economy in the world, and one of the world's largest producers and consumers of renewable energy technologies. Germany had a cumulative 38 GW of PV and 40 GW of wind generation installed in 2014 (IRENA 2015a). Germany has a strong manufacturing sector overall, an open and transparent trading system, and policies that support clean energy deployment.

Key Findings

- In 2014, manufacturing of PV modules, wind turbine components, and Li-ion batteries for vehicles contributed a total of 6.3 billion USD value added (direct and indirect) to Germany's GDP. The highest levels of total value added supported by clean energy manufacturing technologies were 4.8 billion USD from wind components, 1.4 billion USD from c-Si PV, and 61 million USD from Li-ion battery cells for automobiles.
- Germany's PV module manufacturers achieved an average utilization rate of 49%, below the global average of 55%. Germany's Li-ion cell manufacturers averaged 76%, well above the global average 41% for Li-ion cells.
- For the four technologies considered, in 2014, exports totaled 7.2 billion USD and imports totaled 5.4 billion USD, leaving Germany with an overall positive balance of trade (1.7 billion USD).[32] The top trading partners with Germany were China, Taiwan, Malaysia, Canada, and South Korea. Among clean energy manufacturing products, Germany exported the most wind generator sets while importing the most PV cells and modules.

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 8.9 billion USD in revenue from manufacturing of PV modules, wind turbine components, LED packages, and Li-ion battery cells for vehicles supported 6.3 billion USD of value added (3.4 billion USD direct and 2.8 billion USD indirect) in Germany (see Figure 12-1). Across the technology supply chains, the highest total value added came from wind components (4.8 billion USD), c-Si PV modules (1.4 billion USD), and Li-ion batteries (61 million USD).[33]

Economy

- GDP (nominal USD, 2014): 3,868 billion (World Bank 2016)
- Economy-wide value added contribution: 48% of all economic activity (gross output) in 2014
- Import contribution: 11% of gross output, 2014 (World Bank 2016)
- GDP growth rate (five year average 2010–2014): 2.0% (World Bank 2016)
- Manufacturing, value added (% of GDP, 2013): 22.6 (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 1.0

Trade

- Total imports (USD, 2014): 1,215 billion (WITS)
- Total exports (USD, 2014): 1,498 billion (WITS)
- Main trading partners (exports): United States, France, UK, Netherlands, China
- Main trading partners (imports): Netherlands, France, China, Belgium
- Manufacturing share (exports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 183,590 MW (BNEF 2016)
- Renewable share: 47.8%
- Total investment in clean energy (USD, 2014): 18.9 billion (BNEF 2016)

National RE and EE Targets

- 18% renewable energy in final energy consumption by 2020, progressing to 60% by 2050
- 20% reduction in primary energy consumption by 2020 (compared with 2008 levels), progressing to 50% reduction by 2050

32. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

33. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

Manufacturing of wind turbine components, PV modules, and Li-ion batteries generated more direct than indirect value added across the supply chain.

Clean energy manufacturers in Germany retain relatively high portions of direct value added compared to other economies—38% for Germany and 25% for the 12-economy average. This is consistent across all of the clean energy technologies considered, with Germany's clean energy manufacturers retaining 42%, 42%, and 37%, respectively, in direct value added for manufacture of c-Si PV modules, Li-ion battery cells, and wind turbine components.

For total (direct and indirect) value added retained (shown in Figure 12-1), Germany trails Brazil (82%) and the United States (80%) and is tied with Japan (70%).

The percentage of direct value added across all industries that Germany retains per dollar of revenue is 48%, placing Germany eighth out of the 12 economies considered in this report. This retained value added is still higher than the average of the 12 economies considered (46%) because the domestic supply chain is more developed, and businesses, on average, have higher value added per dollar of revenue than in other economies. Germany

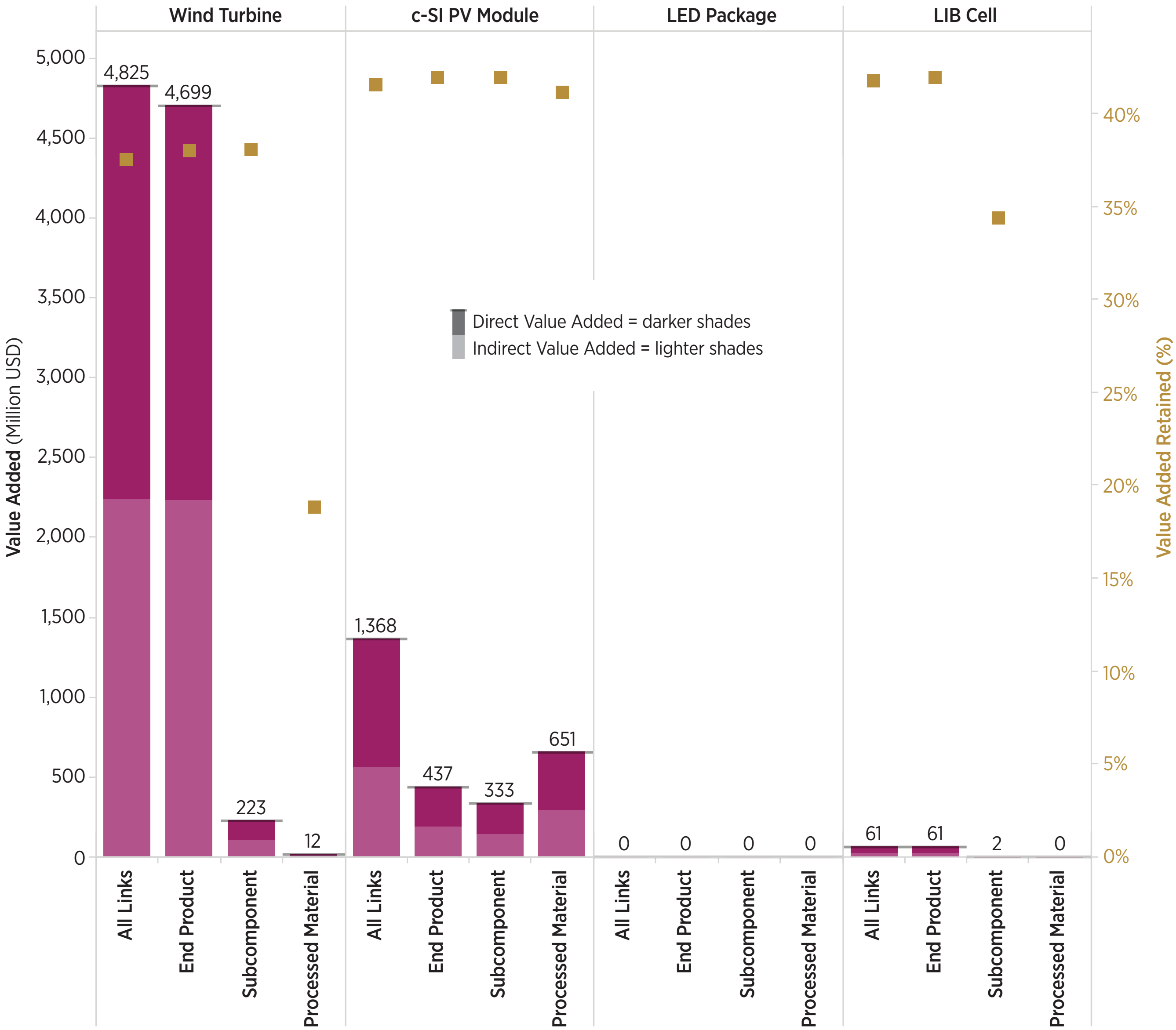


Figure 12-1. Germany's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

relies more heavily on imported intermediates than do 8 considered economies. Only Taiwan, Malaysia, and Korea spend a higher percentage of gross output on imports.

German expenditures on domestic inputs constitute a percentage of gross output that is lower than the 12-economy average (40% vs. 42%), while expenditures on imports as a percent of gross output are at the 12-economy average (11%).

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

Germany is renowned for its manufacturing successes (Wessner 2013 and Gummer 2014). In 2014, Germany's manufacturing sector contributed 22.6% to national GDP, equivalent to 866 billion USD in 2014 (World Bank 2016). Recent German manufacturing success is attributed to Germany's commitment to exports. German exports are supported by a number of factors, among them: a devalued currency at the adoption of the Euro (The Economist 2012), a suite of labor market reforms designed to free the labor market and encourage the employment of Germany's under-utilized low-skilled labor

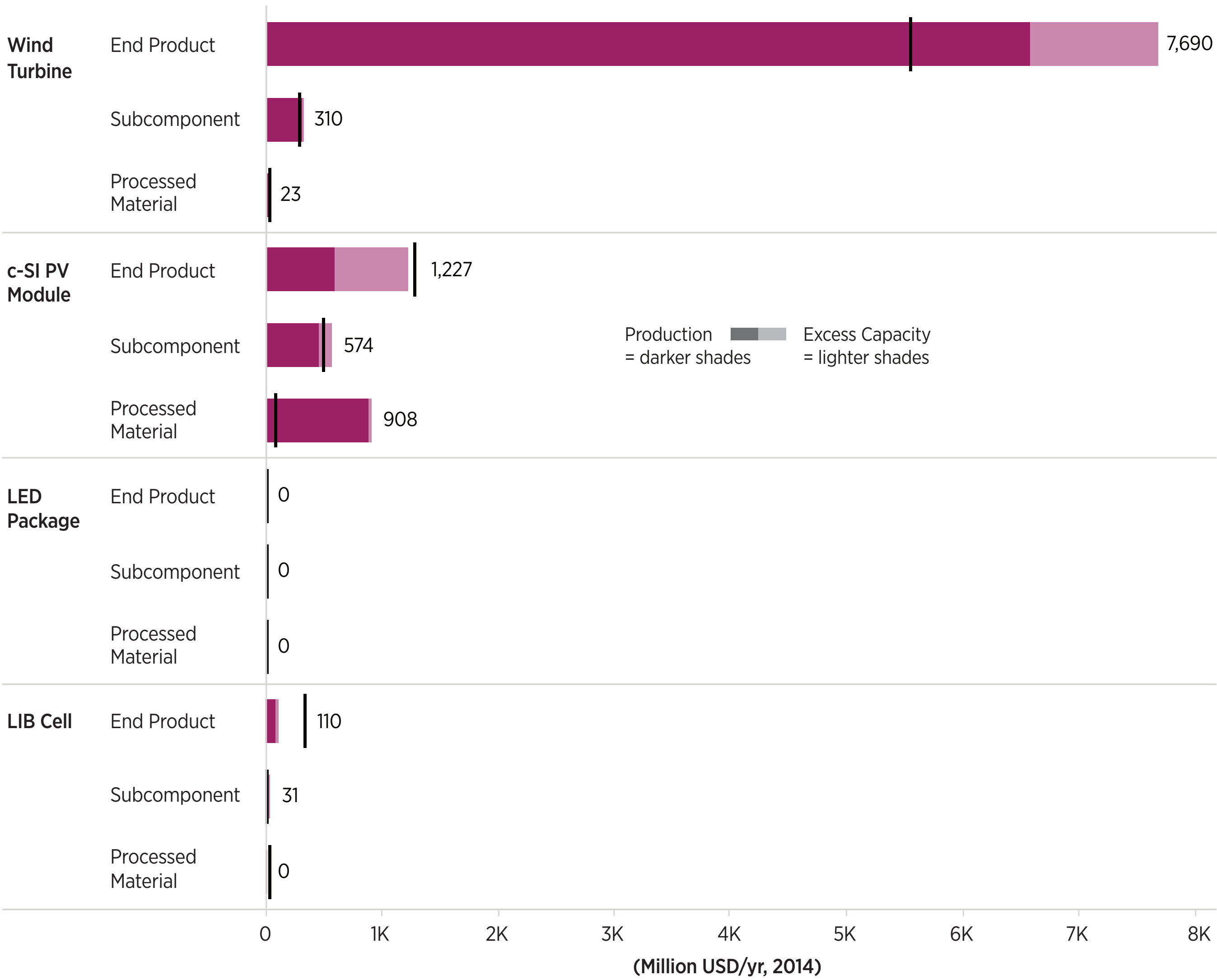


Figure 12-2. Germany's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, 2014. See methodology report for data quality discussion.

(The Economist 2013), a highly developed manufacturing capacity in machine tools, chemicals, and cars, and a strong national commitment to vocational education. Germany's manufacturing success is also supported by the government-industry-university partnership, Fraunhofer-Gesellshaft (Franuhofer Society), an independent non-governmental organization established to conduct high-quality applied research with practical industrial value, with a focus on supporting small and medium-size firms.

In 2014, Germany has a small base of wind and solar-related manufacturing across the supply chain. Germany also hosted a relatively small amount of Li-ion battery cell manufacturing and did not manufacture LED packages in 2014. Figure 12-2 shows Germany's 2014 demand, manufacturing capacity, and production for the four technologies covered in this analysis.

Germany hosts the second highest share of nacelle manufacturing capacity, and the third highest share of blade and generator manufacturing capacity of the economies listed in this report. In 2014, Germany was home to 9,000 MW of nacelle (terrestrial), 5,000 MW of blade, 5,800 MW of generator, and 5,400 MW of tower manufacturing capacity. Germany has established c-Si PV manufacturing capacity across all supply chain segments. In 2014, Germany hosted 1,700 MW (2% of the global total) of module, 1,000 MW (2%) of cell, 800 MW (1%) of wafer, and 9,900 MW (13%) of polysilicon manufacturing capacity. These capacities were the ninth largest share of module, sixth largest share of cell and wafer, and the fourth largest share of polysilicon manufacturing capacity of the economies listed in this report. In 2014, Germany was home to a minor amount of LDV Li-ion cell and separator manufacturing capacity, totaling 300 MWh (1% of the global total) of annual cell manufacturing capacity, and 1,200 MWh (3% of the global total) of annual separator manufacturing capacity.

Germany's PV module manufacturers achieved an average utilization rate of 49%, below the 12-economy average of 55%. Germany's Li-ion cell manufacturers averaged 76%, above the global average of 41% for Li-ion cells, and its wind turbine manufacturers averaged 82%, above the global average of 57%.

With respect to demand:

- Annual German demand for land-based wind turbines was 5,300 MW, and constituted the second largest single economy annual demand market. As of 2014, Germany has installed a cumulative total of 39,000 MW of wind power, making it third globally behind China and the United States.
- German annual demand for PV modules was 1,800 MW in 2014, or 5% of global annual demand. However, Germany was an early PV adopter, and the German market was the world's largest for many years. From 2005 through 2015, Germany installed 25% of all grid-connected PV capacity globally.
- German annual demand for Li-ion cells was 900 MWh in 2014, or 9% of the global total. This demand was driven in part by Germany's advanced automobile manufacturing capabilities and supportive electric vehicle policy framework.

Trade Landscape: Balance of Trade and Trade Flows

Germany maintains an open and transparent trade system aligned with the European Union's common policies and laws regarding trade. With respect to clean energy manufacturing, the EU has established import duties on PV products to counteract alleged Chinese subsidies and price-cutting. Specifically, the EU has established import duties on Chinese solar glass and on Chinese PV products through 2019 (European Commission 2016c). In response, China placed duties on polysilicon from EU economies beginning in May 2014 (MOFCOM 2014). Figures 12-3 through 12-7 show Germany's balance of trade in the selected clean energy technologies both collectively and individually.

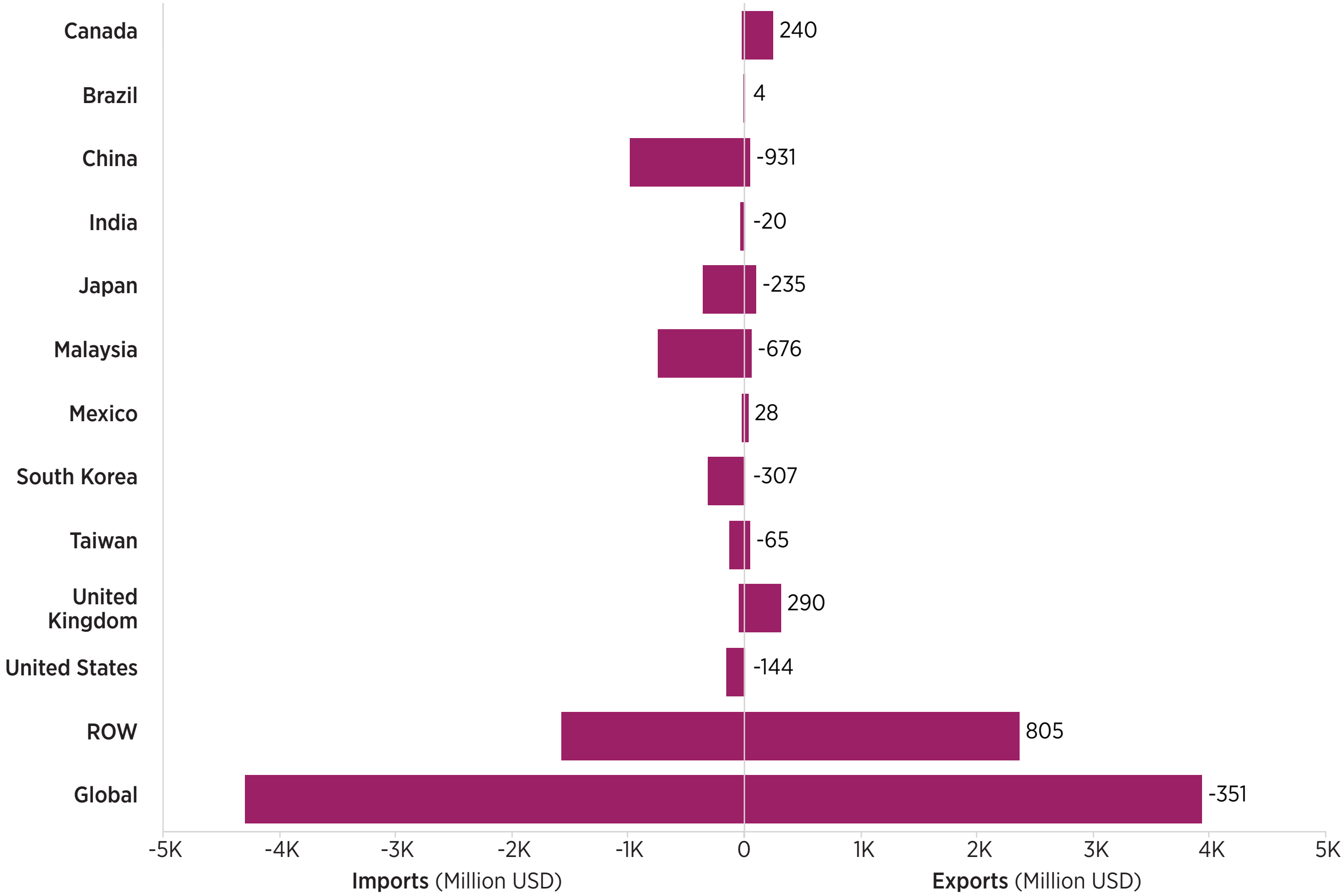


Figure 12-3. Germany's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

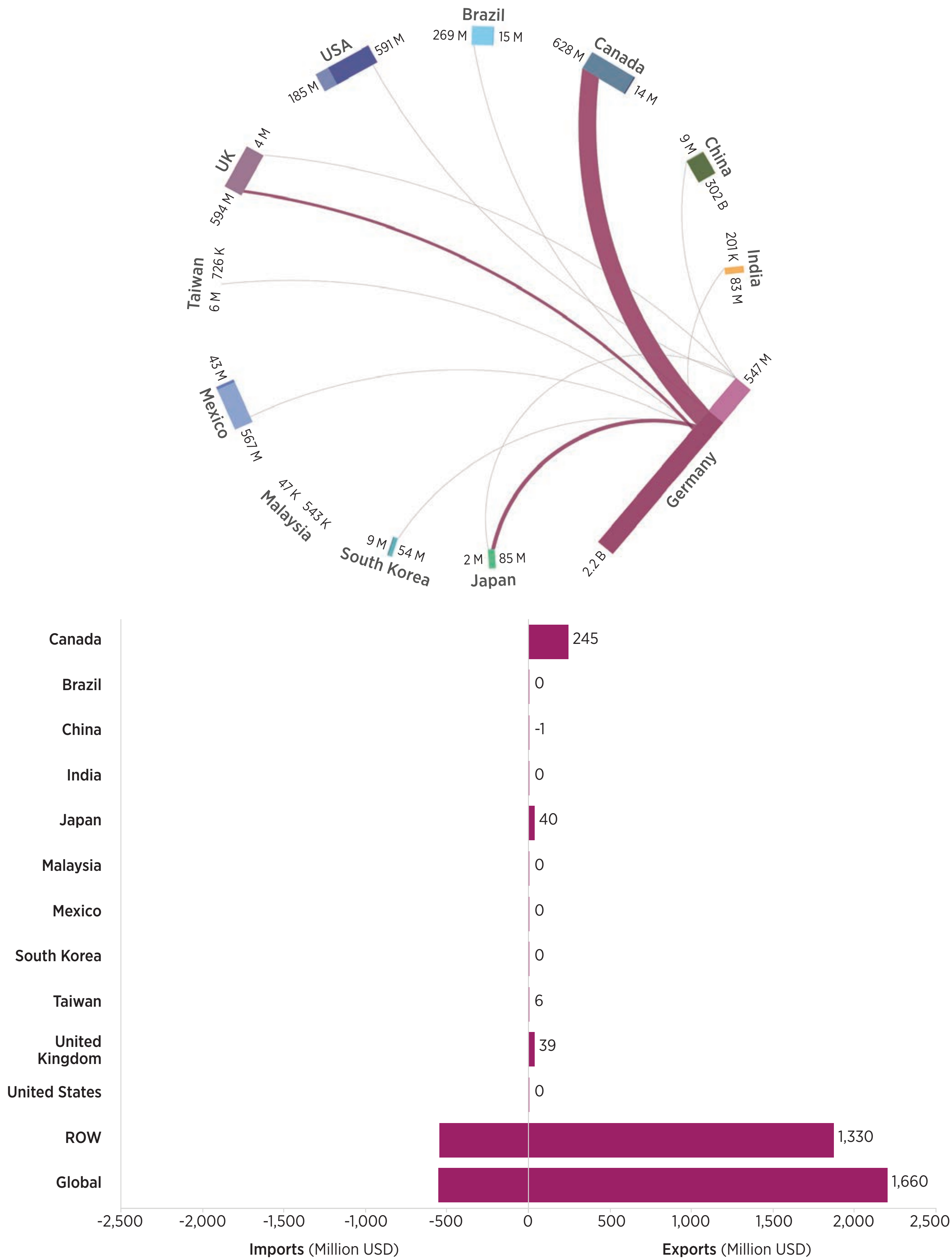


Figure 12-4. Germany's 2014 Trade Flows and Balance of Trade for Wind Turbine Generator Sets. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

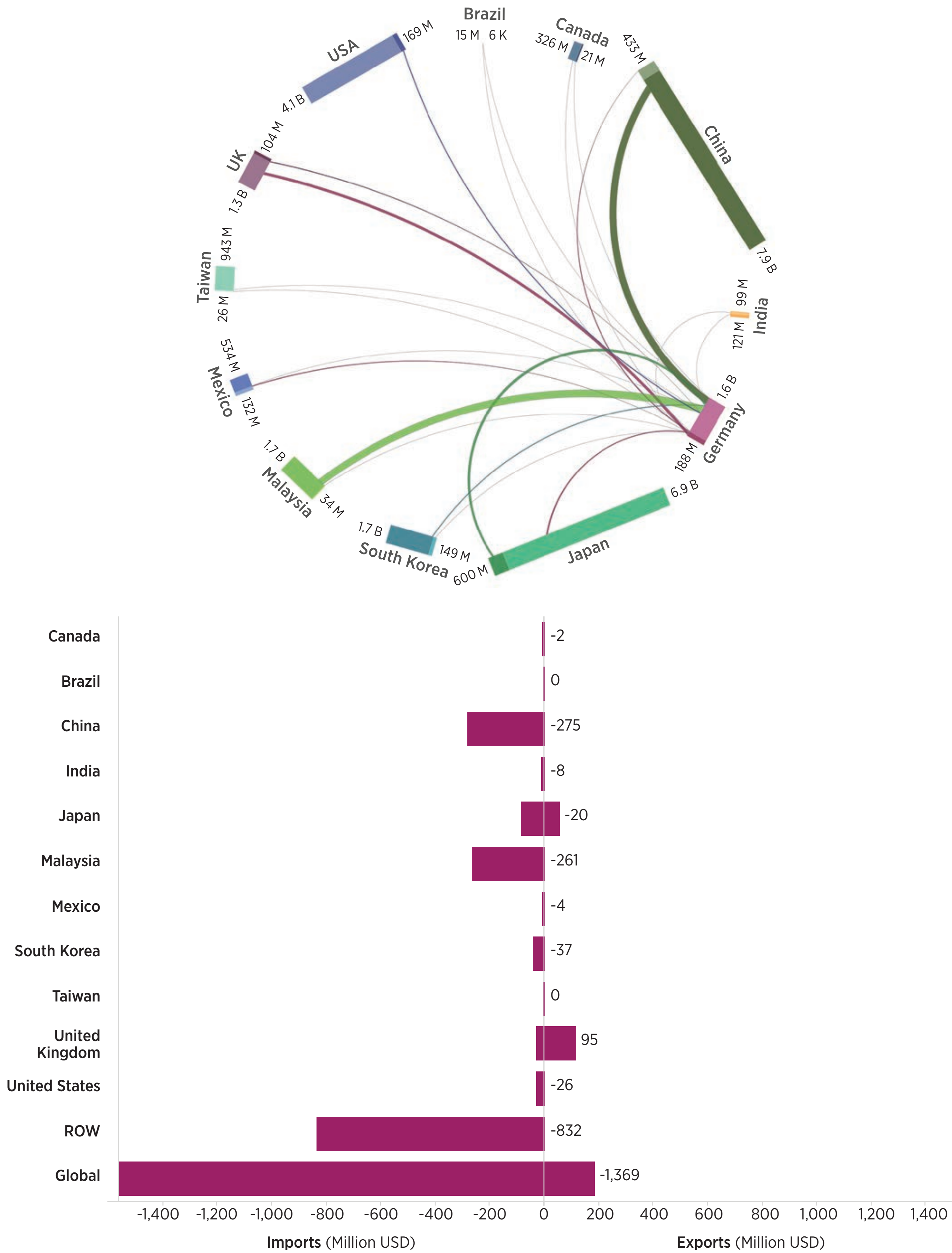


Figure 12-5. Germany's 2014 Trade Flows and Balance of Trade for PV Modules. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

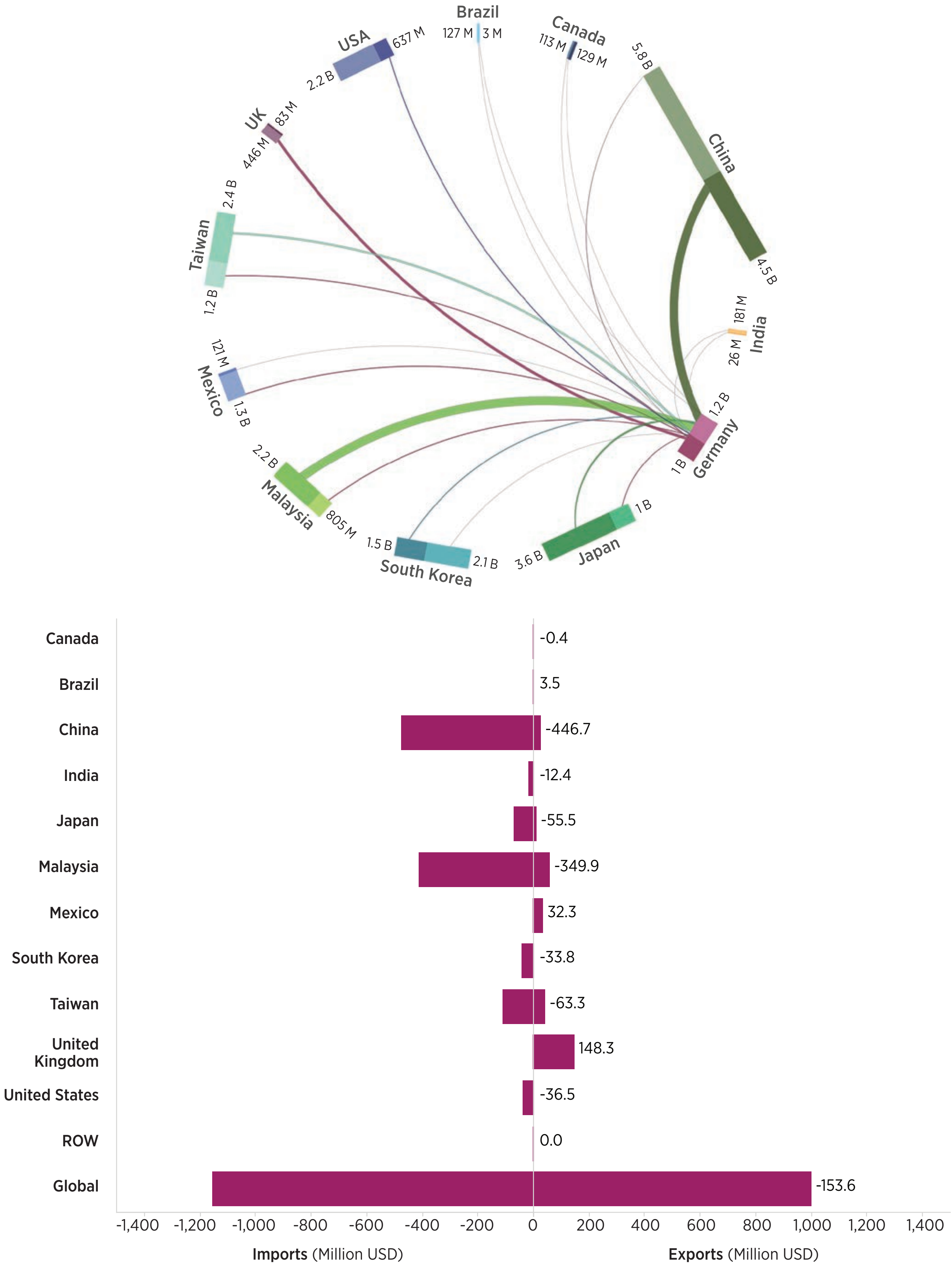


Figure 12-6. Germany's 2014 Trade Flows and Balance of Trade for LED Packages. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

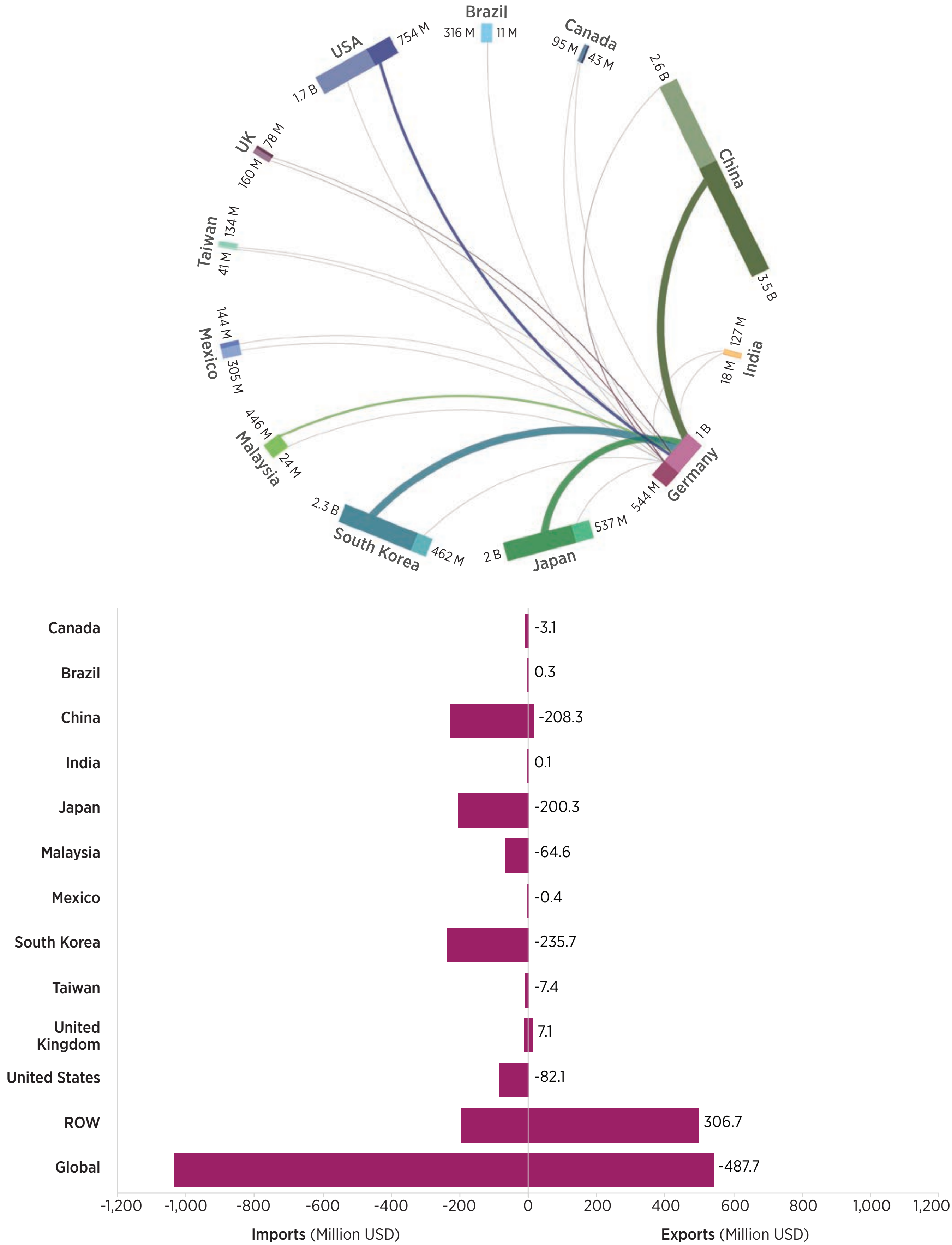


Figure 12-7. Germany's 2014 Trade Flows and Balance of Trade for Li-ion Battery Cells. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

13 | India: Clean Energy Manufacturing Profile

India is one of the world's largest economies with a GDP of just over 2 trillion USD and a four-year growth rate of just over 7%. Energy demand has also increased in that time, and generation capacity has expanded to 245 GW. India had a cumulative 3 GW of PV and 22 GW of wind generation installed in 2014 (IRENA 2015a). Capacity is expected to grow to include 100 GW of solar and 60 GW of wind by 2022. Clean energy manufacturing is expanding to meet domestic demand. A range of laws, policies and incentives to boost international competitiveness and meet India's national and international climate change commitments have driven clean energy development.

Key Findings

- In 2014, Indian manufacturing of wind turbine components and PV modules supported a total of 1.6 billion USD in value added (direct and indirect). The highest levels of value added supported by clean energy manufacturing technologies was 1.4 billion USD from wind components and 212 million USD from c-Si PV.
- Of the economies included in this analysis, India hosted the fourth-highest shares of manufacturing capacity for nacelles, blades, towers, and generators.
- For the four selected technologies, in 2014, exports totaled 276 million USD and imports totaled 994 million USD, leaving India with an overall negative balance of trade (-718 million USD). The top trading partners with India were China, the United States, the United Kingdom, and Brazil. Among clean energy manufacturing products, India exported and imported the most PV cells and modules.

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 3.1 billion USD in revenue from manufacturing of PV modules and wind turbine components supported 1.6 billion USD of value added (642 Million direct VA and 965 indirect VA)) in India (see Figure 13-1). Across the technology supply chains, the highest total value added came from wind components (1.4 billion USD) and PV modules (212 million USD).[34] For India, manufacturing of wind turbine components[35] and of PV modules generated more indirect than direct value added across the supply chain.

Economy

- GDP (nominal USD, 2014): 2,048 billion (World Bank 2016)
- Economy-wide value added contribution: 49% of all economic activity (gross output) in 2014
- Import contribution: 11% of gross output, 2014
- GDP growth rate (five year average 2010–2014): 7.2% (World Bank 2016)
- Manufacturing, value added (% of GDP 2013): 17.1% (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.3

Trade

- Total imports (USD, 2014): 318 billion (WITS)
- Total exports (USD, 2014): 459 billion (WITS)
- Main trading partners: China, Saudi Arabia (imports, 2014)
- Main trading partners: United States, UAE (exports, 2014) (CIA 2016)

Energy Sector

- Total installed generation capacity (2014): 271.73 GW (Central Statistics Office 2016)
- Renewable share (excluding large hydro): 11.8% (Central Statistics Office 2015; IRENA
- Total investment in clean energy (USD, 2014): 7.4 billion USD (CIA 2016)

RE and EE Targets

- 175 GW of RE generating capacity by 2022
- 3.9% reduction in energy consumption by manufacturing by 2018–19 (CDP 2016)

34. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

35. Value added from wind blade manufacturing only includes land-based wind.

In India, manufacturers of the four selected clean energy technologies support relatively low portions of direct value added retained (21%) compared to the 12-economy average of 25%.

Similarly, for total (direct and indirect) value added retained (shown in Table A-2), India sits below the 12-economy average at 52% in comparison with an average of 55% across all economies in this report.

The ratio of inputs economy-wide in proportion to gross output in India is 11%, equal to the 12-economy average. Similarly, the proportion of economy-wide value added to output is 49%, also similar to the 46% average across economies in this report (OECD 2015b). Variations on these averages are driven by the specific industries affected by clean energy manufacturing.

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

India's manufacturing sector accounted for 17.1% of its GDP in 2014, equivalent to 350 billion USD. Indian manufacturing has rebounded in recent years with a national goal to make manufacturing 25% of GDP by 2022. As part of this push, the "Make in India" campaign was launched to bolster domestic manufacturing capacity and make India a manufacturing hub. "Make in

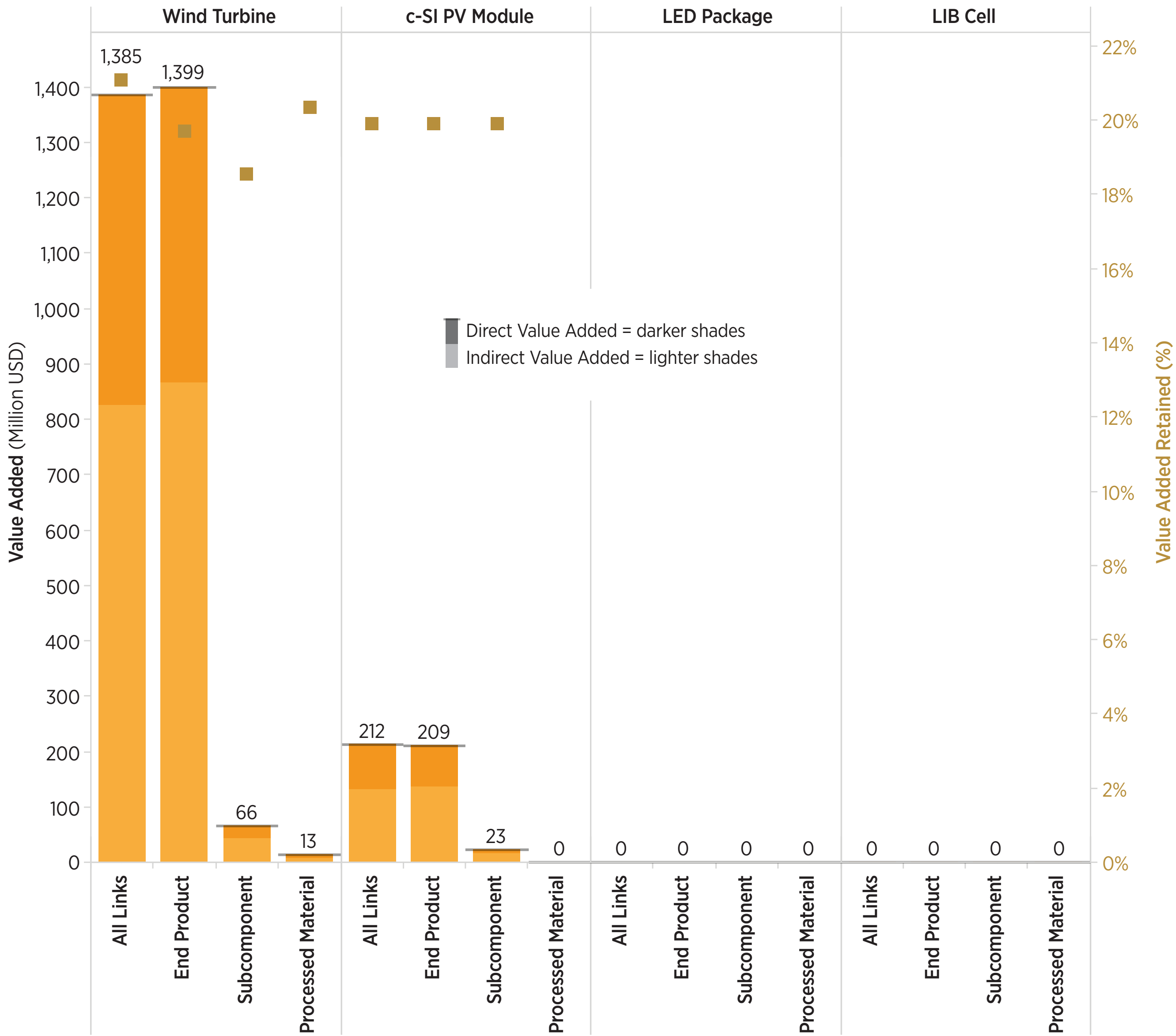


Figure 13-1. India's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

India" seeks to reduce regulatory barriers to investment in manufacturing by foreign companies by increasing the amount of foreign direct investment allowed for manufacturing projects (Make in India 2016).

For clean energy technologies, in 2014 India maintained a strong domestic manufacturing base for wind turbine components and PV module end products, but did not host manufacturing of LED packages or automotive Li-ion batteries in any of the supply chain links included in this study. Figure 13-2 shows India's 2014 manufacturing capacity, production, and demand for the four benchmark technologies.

Among the 12 economies included in this analysis, India hosted the fourth-highest nacelle, blade, tower, and generator manufacturing capacity in 2014. India was home to 7,800 MW of nacelle manufacturing capacity, 6,100 MW of blade capacity, and 3,200 MW of tower, and 4,200 MW of generator capacity. India manufactures c-Si PV end products from inexpensive sub-components from China. In 2014, Indian PV manufacturing capacity was 1,700 MW of modules and 500 MW of cells. Indian module and cell capacities are the seventh- and eighth-largest of the economies in this report, respectively (Energética India 2015).

India's PV module manufacturers achieved an average utilization rate of 30%, below the global average of 55%.

From the demand side:

- Indian wind turbine demand was 2,300 MW in 2014, making it the fourth-largest demand market for wind turbines behind China, the United States, and Brazil.

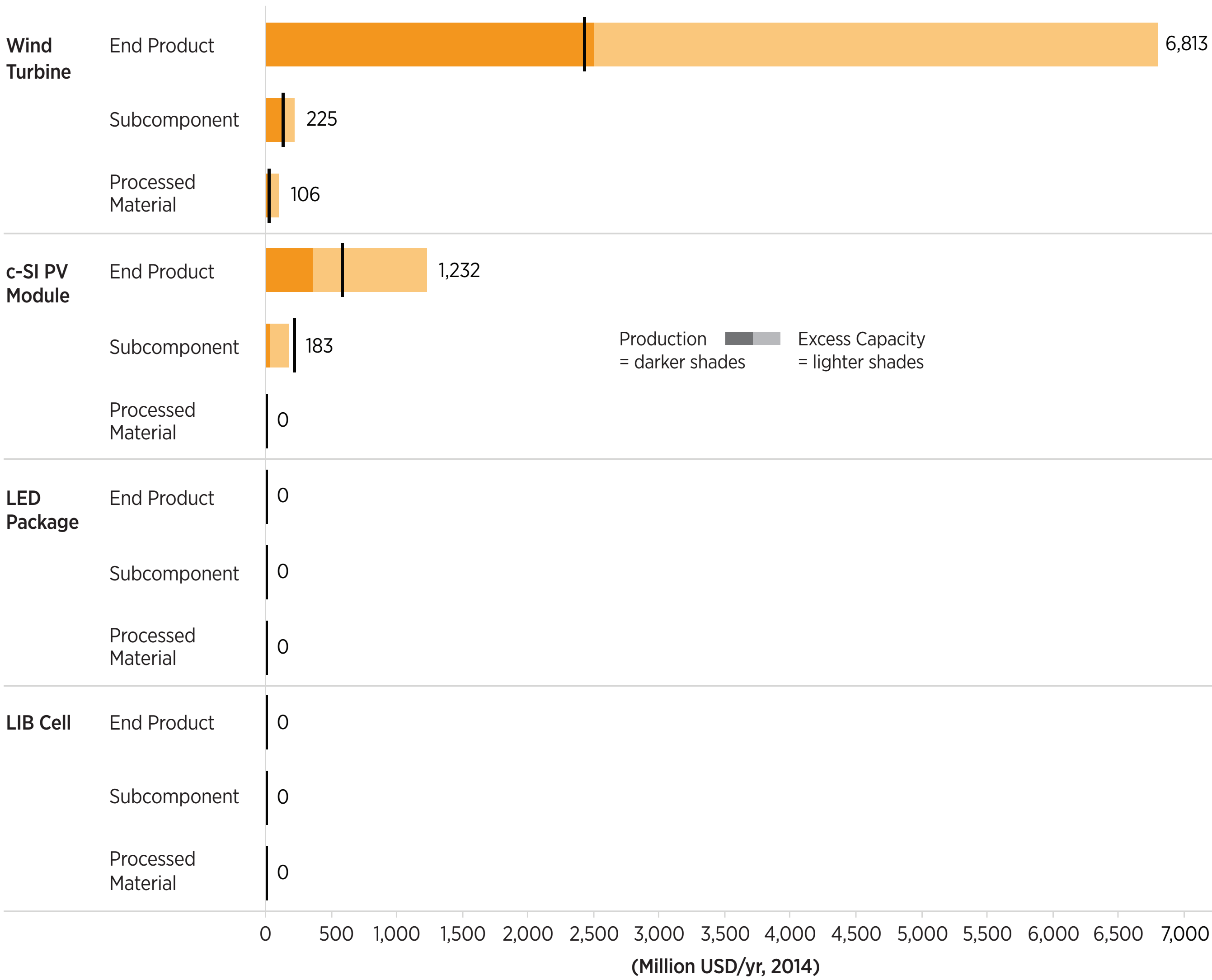


Figure 13-2. India's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, 2014. See methodology report for data quality discussion.

- Indian PV module demand was 800 MW in 2014, making it the sixth-largest market for PV modules of the economies included in this report. India accounted for approximately 2% of total global demand. For comparison, the top 5 demand markets were at least 2,000 MW. However, Indian demand is projected to grow sharply through 2020, and India potentially become the fourth-largest market in terms of total cumulative demand from 2015-2020.
- India's LED market currently generates around 1.3 billion USD, and the Indian government expects the market to grow to 3.6 billion USD by 2020. Their hope is to encourage India industry to supply domestic demand with 50% of LEDs coming from domestic manufacturers (Business Standard 2016). The government is the largest purchaser of LEDs in India purchasing approximately 50% of all LED orders (LEDinside 2014).
- In 2014, there were no significant domestic manufacturers of LDV Li-ion batteries, cells, or components in India. India did not produce significant numbers of electrified vehicles in 2014, meaning automotive-related demand for Li-ion batteries or cells was effectively non-existent. Demand for Li-ion technologies and associated vehicle technologies are expected to grow due to increasing demand bolstered by government policies.

Trade Landscape: Balance of Trade and Trade Flows

India's trade policy focuses on enhancing market access for its exports, making India a significant participant in international trade, and increasing India's share of global exports to 3.5% in 2020. India advocates for the multilateral trading system and is also party to a number of regional trade agreements. (WTO 2015.)

In Figures 13-3 through 13-7, we show the balance of trade and trade flows for the supply chain links for which trade data are available. In 2014, India maintained a positive balance of trade in wind components and a negative balance of trade in PV modules, LED packages, and Li-ion battery cells.

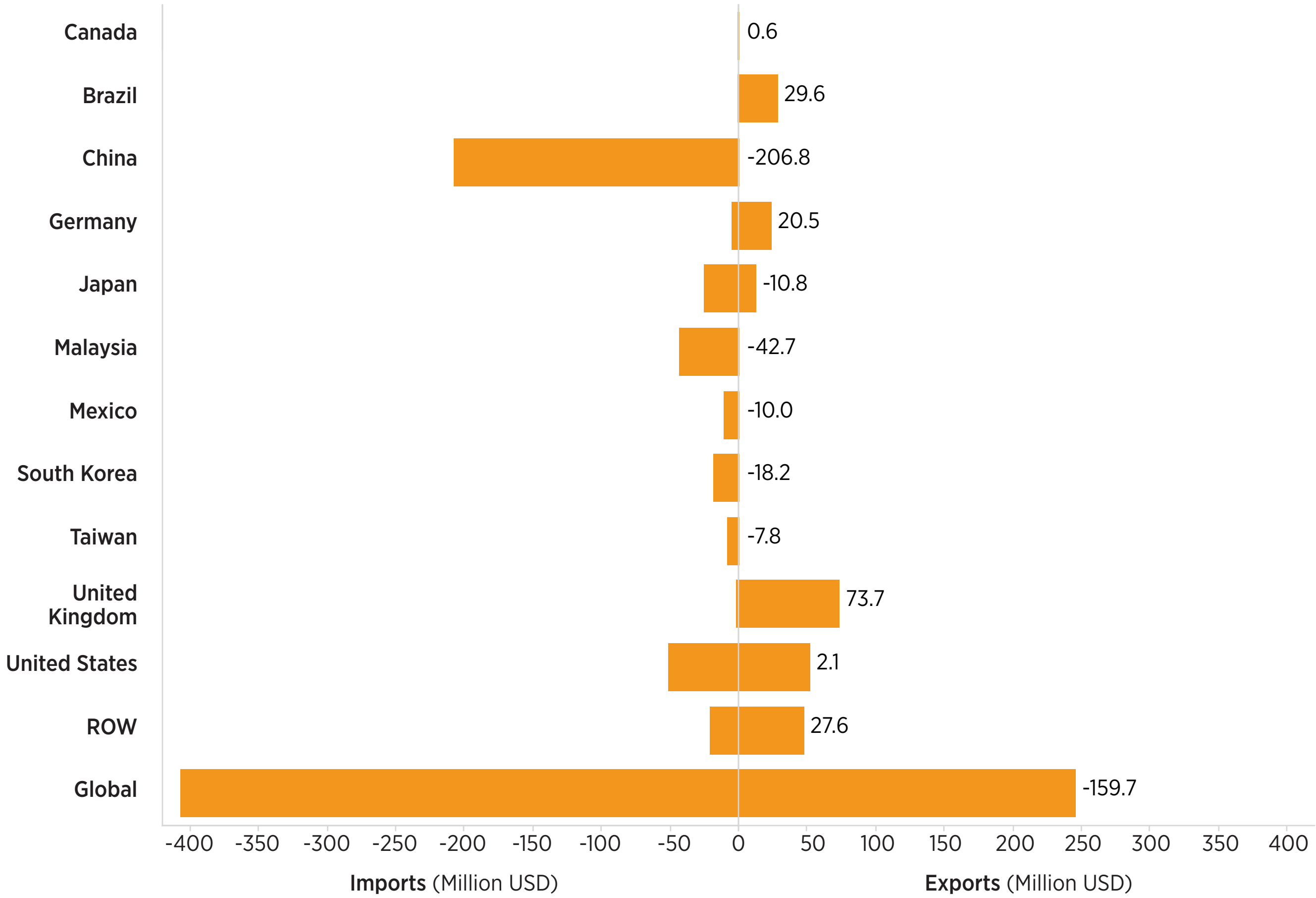
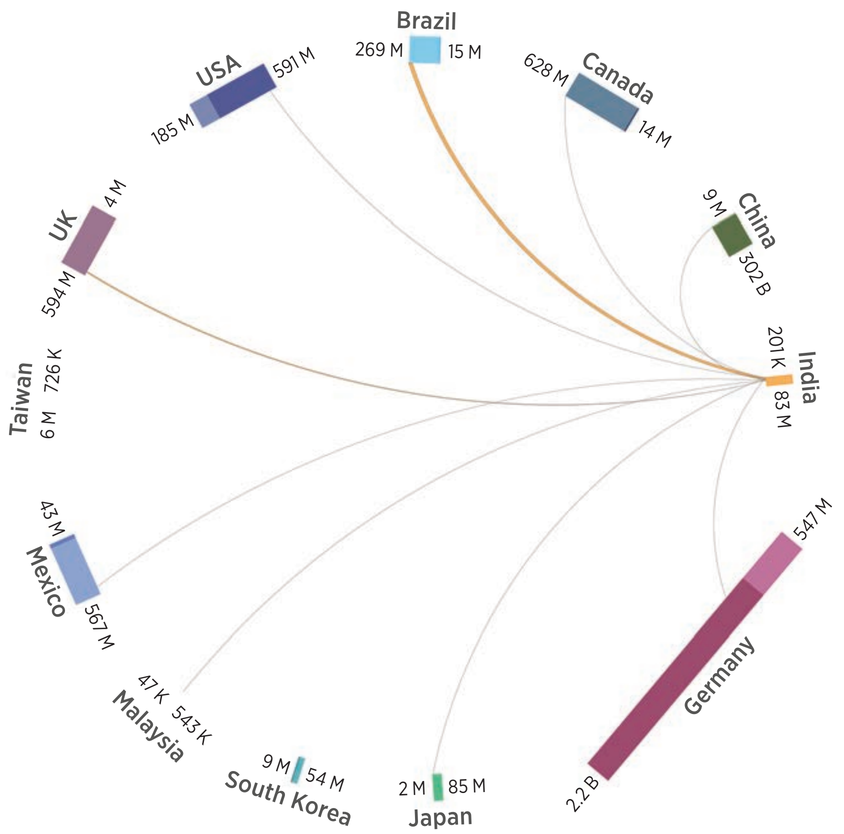


Figure 13-3. India's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.



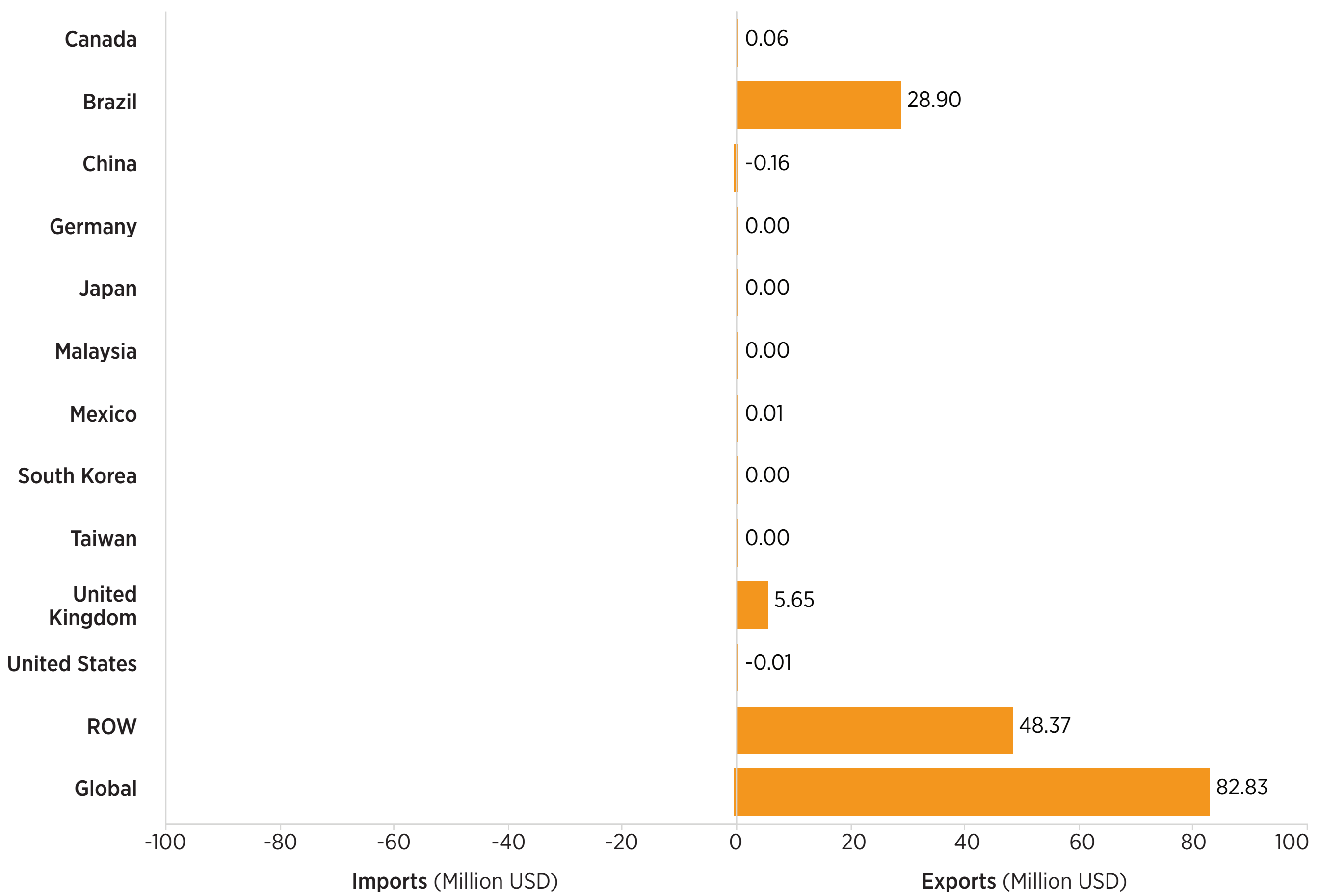


Figure 13-4. Trade between India and key partners in wind turbine generator sets, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

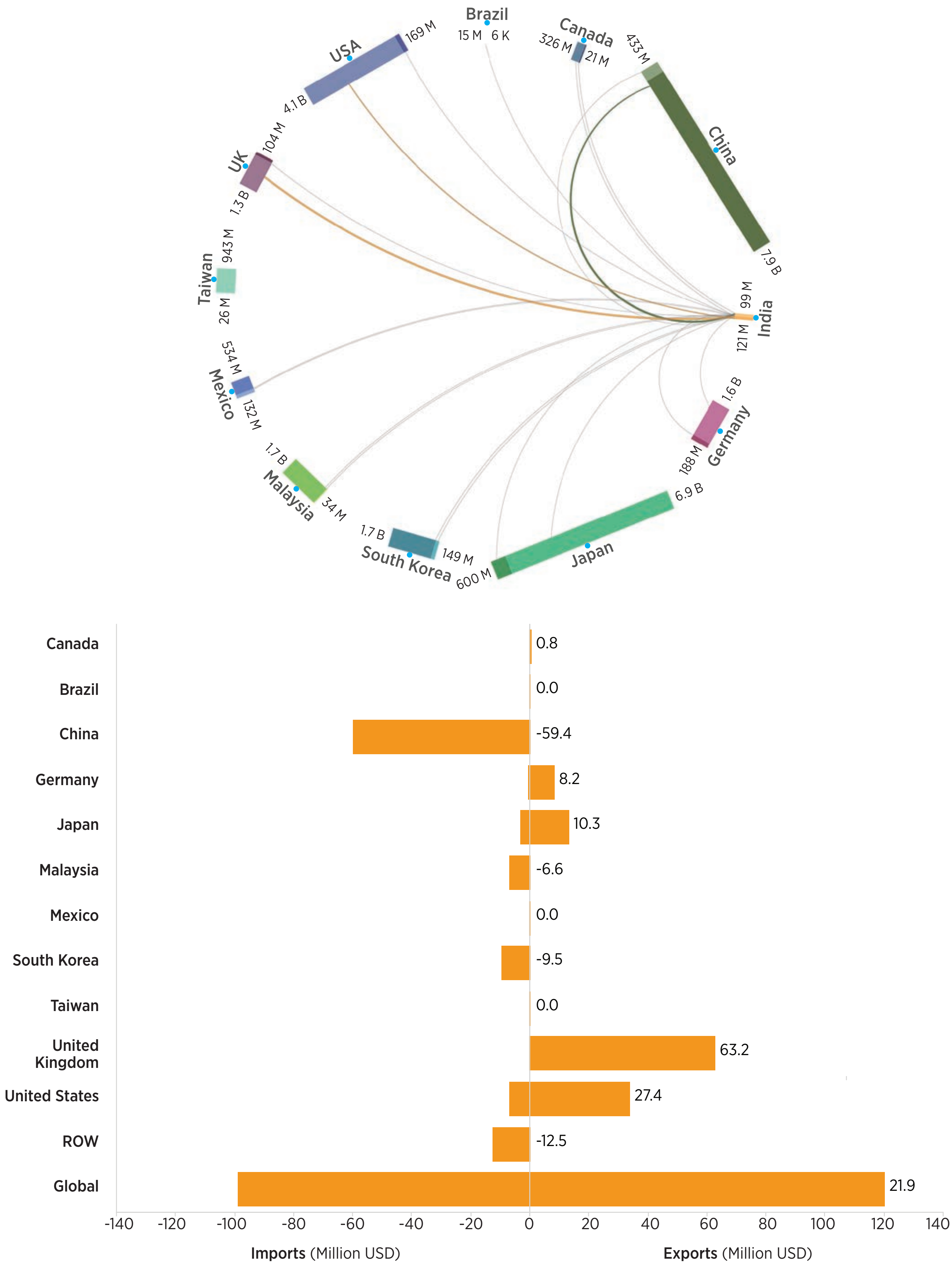
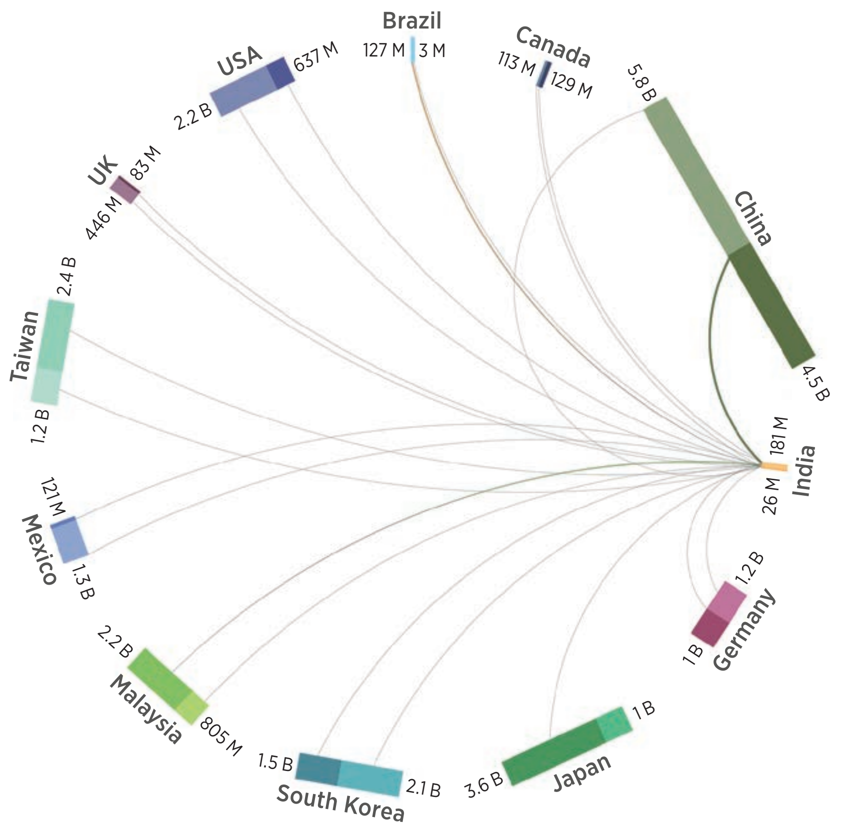


Figure 13-5. Trade between India and key partners in c-SI PV modules, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



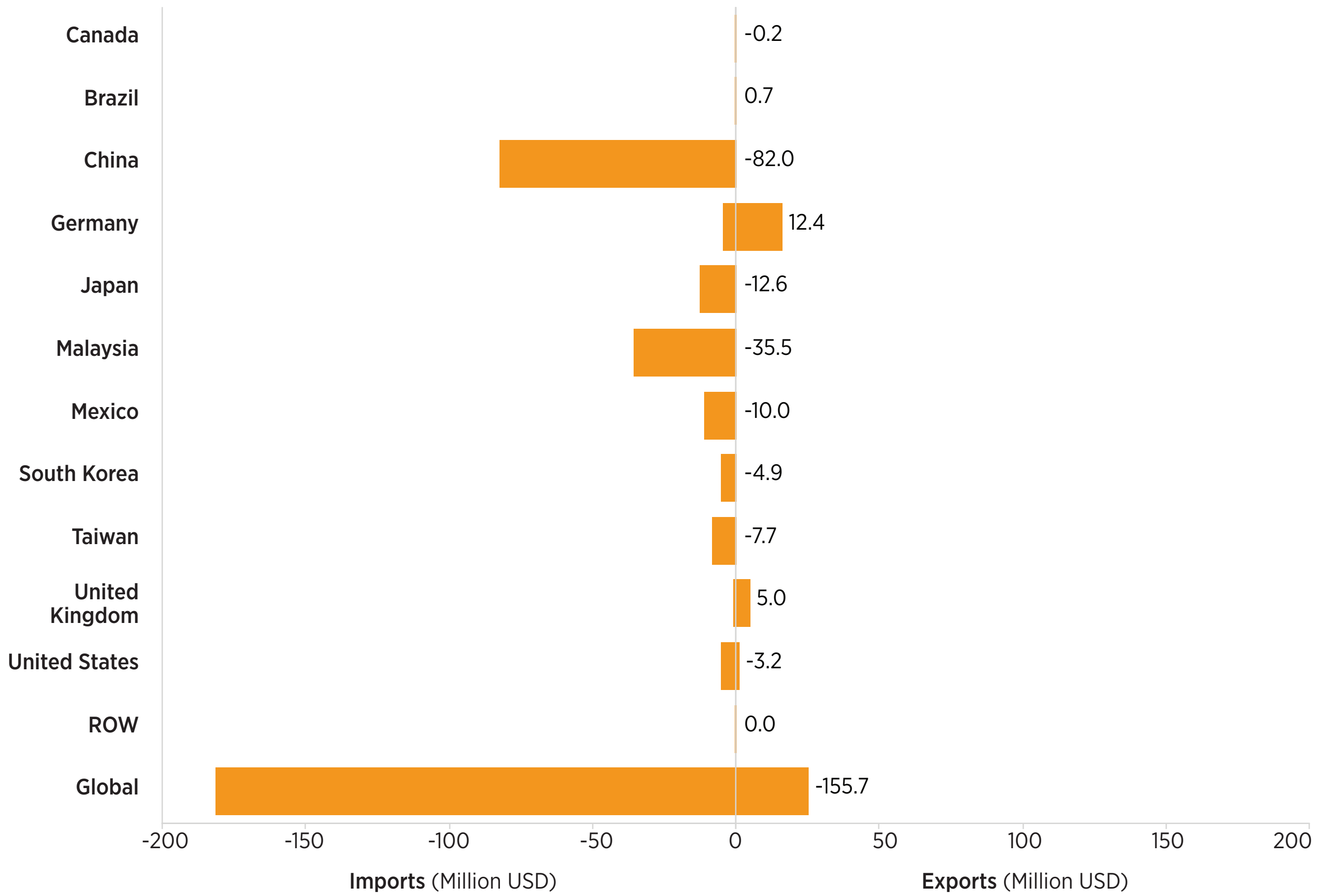
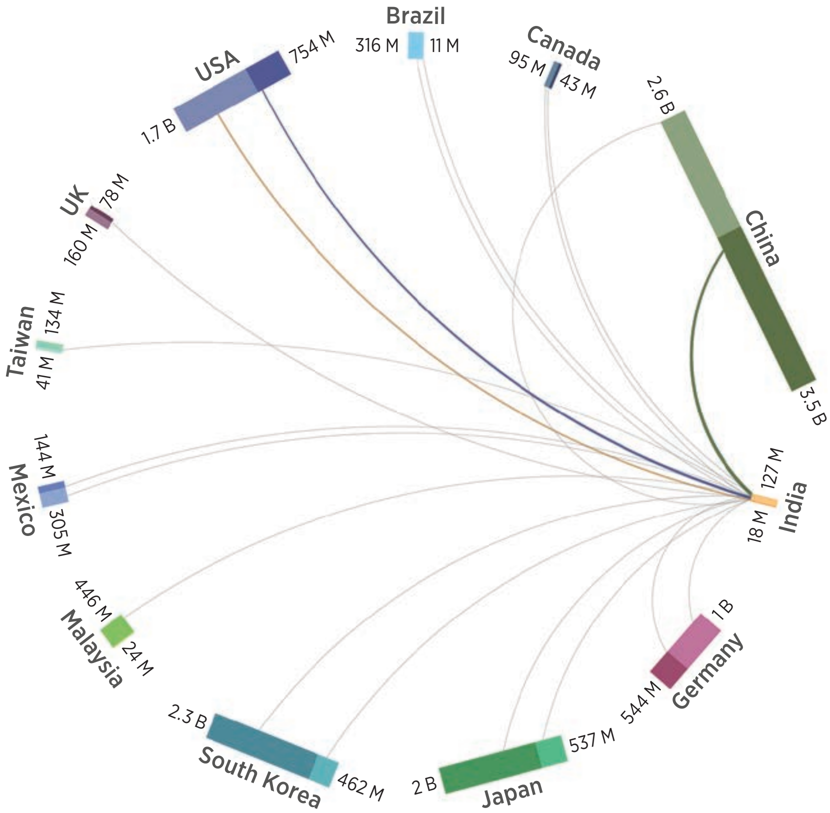


Figure 13-6. Trade between India and key partners in LED packages, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



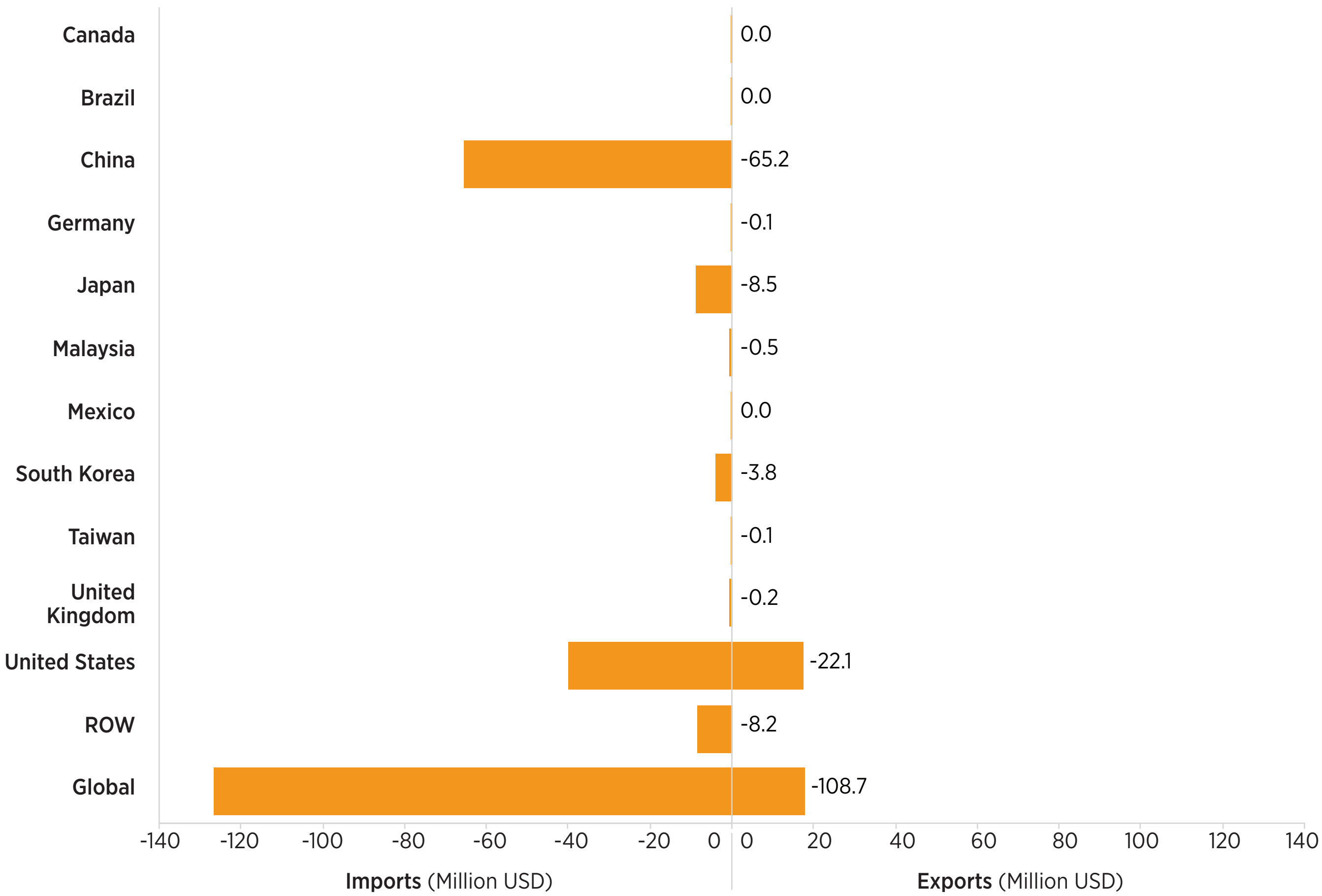


Figure 13-7. Trade between India and key partners in Li-ion cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

14 | Japan: Clean Energy Manufacturing Profile

Japan has one of the world's largest economies, with a GDP of over 4.6 trillion USD. Today Japan is a large producer of clean energy components. Japan had a cumulative 23 GW of PV and 3 GW of wind generation installed in 2014 (IRENA 2015a). Strong policy support built the Japanese market, and the closure of Japan's nuclear power plants following the 2011 Fukushima nuclear plant incident has led to additional growth in renewable energy demand.

Key Findings

- In 2014, manufacturing of PV modules, wind turbine components, LED packages, and Li-ion cells for vehicles supported 7.1 billion USD in value added (direct and indirect) in Japan. The highest levels of value added supported by clean energy manufacturing technologies was 3.4 billion USD from LEDs, followed by c-Si PV (2.1 billion USD), batteries (1.3 billion USD), and wind (326 million USD).
- For the selected clean energy technologies, Japanese manufacturing utilization rates are generally at or above global averages. This is potentially indicative of a more conservative approach taken by Japanese firms; manufacturing capacity has grown in closer balance with demand.
- For the four technologies considered, in 2014, exports totaled 7.3 billion USD and imports totaled 10.7 billion USD, leaving Japan with an overall negative balance of trade (-3.5 billion USD).[36] Top export partners were China, United States, and South Korea; top import partners were China, United States, and Taiwan. Japan's highest trade balances were in LED packages (2.6 billion USD) and Li-ion battery cells (1.5 billion USD).

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 10.2 billion USD in revenue from manufacturing of PV modules, wind turbine components, LED packages, and Li-ion battery cells for vehicles supported 7.1 billion USD of value added (3.8 billion USD direct, 3.4 billion USD indirect) in Japan (see Figure 14-1). Across the technology supply chains, the highest total value added came from LED packages (3.4 billion USD), PV modules (2.1 billion USD), and Li-ion battery cells (2.6 billion USD).[37]

Economy

- GDP (nominal USD, 2014):4,601 billion (World Bank 2016)
- Economy-wide value added contribution: 52% of all economic activity (gross output) in 2014
- Import contribution: (% of gross output, 2014): 6%
- Manufacturing, value added (% of GDP 2013): 18.5% (World Bank 2016)[38]
- Five-year GDP growth rate (2010–2014): 3.7% (World Bank 2016)[39]
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 1.0

Trade

- Total imports (USD, 2014): 812 billion (WITS)
- Total exports (USD, 2014): 690 billion (WITS)
- Main trading partners: United States, China, South Korea, Hong Kong, Thailand (exports)
- Main trading partners: China, United States, Australia, South Korea (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 230 GW (EIA Beta 2015)
- Renewable share (excluding large hydro): 14.9%
- Total investment in clean energy (USD, 2014): 41 billion USD4 (BNEF 2016)

RE and EE Targets

- 10% of total national energy supply from renewable energy by 2020
- 100% LED lighting by 2020
- 100% LED lighting by 2020

38. World Bank national accounts data, and OECD National Accounts data files

39. World Bank national accounts data, and OECD National Accounts data files

36. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

37. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

Manufacturing of wind turbine components[40], c-Si PV modules, and LED packages generated more direct than indirect value added across the supply chain. In Japan, the manufacturers of these products create more economic value than their greater supply chains within Japan. In contrast, Li-ion battery cell manufacturing generated more indirect than direct value added, showing the significance of Japanese suppliers for producers of battery cells and their subcomponents.

Clean energy manufacturers in Japan retain relatively high portions of direct value added compared to other economies—37% for Japan and 25% for the 12-economy average. This is consistent across all of the clean energy technologies considered, ranging from 34% for wind to 37% for both LEDs and c-Si PV. Value added per dollar of revenue for batteries was 36%.[41]

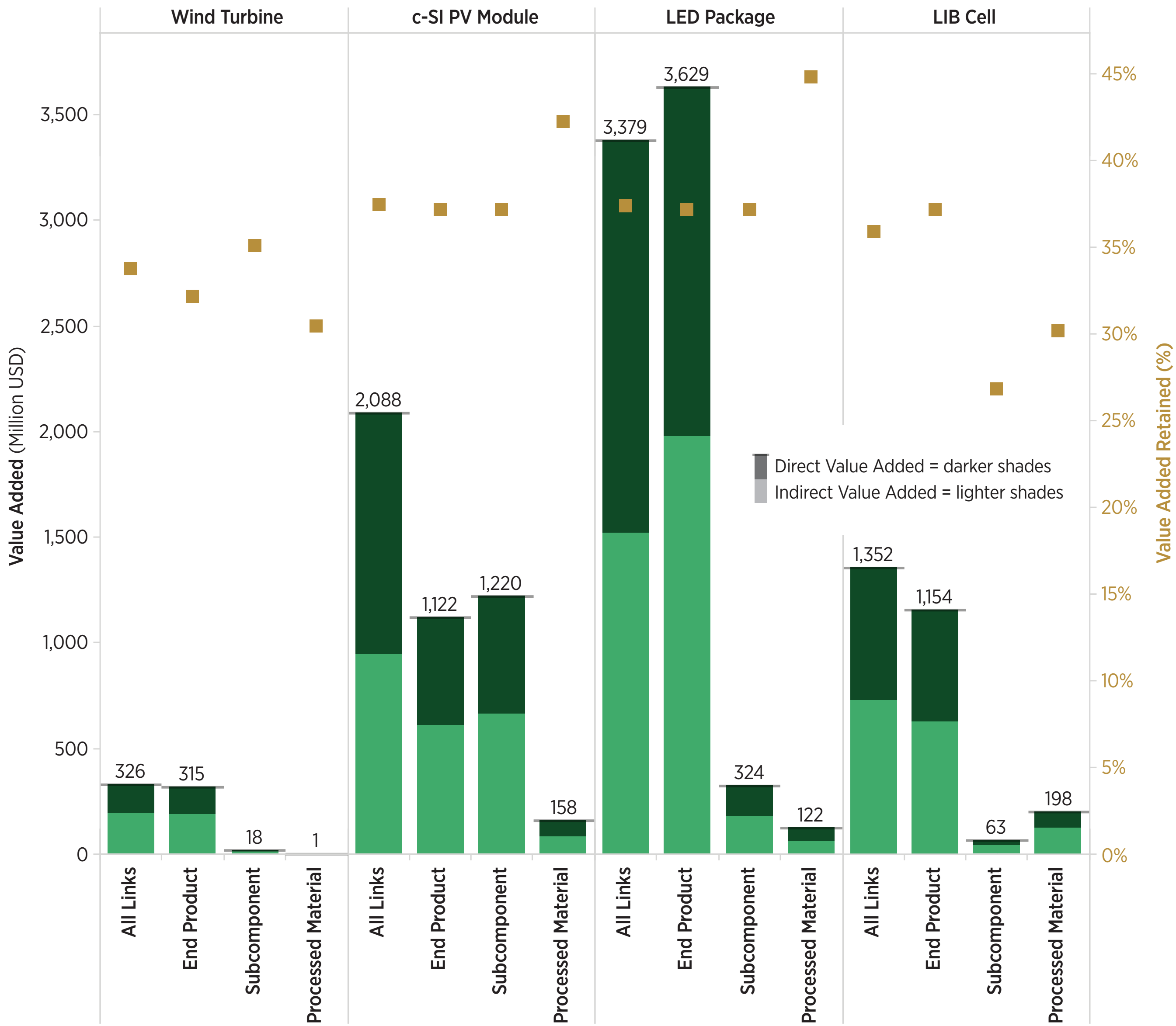


Figure 14-1. Japan's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

40. Value added from wind blade manufacturing only includes land-based wind.

41. OECD STAN (2015)

When examining direct and indirect value added as a portion of revenue across the 12-economy study group, Japan trails only Brazil (82%) and the United States (80%) with a 70% ratio. Generally, Japan earns high value added as a portion of overall economic activity (gross output) across all industries economy-wide.

The relatively greater economy-wide as well as direct and indirect impacts of clean energy manufacturing are driven by characteristics of Japan's economy, including relatively low imports, well-developed domestic supply chains, and high value added. Domestic supply chains mean that manufacturers rely less on imports; thus, businesses that supply goods and services to manufacturers support value added in Japan. The portion of revenue that leaves the economy to pay for imported inputs that Japanese businesses use in order to produce their goods or services is 6% compared to the 12 economy average of 11%. Value added as a portion of revenue is 52%, greater than the 46% average.[42] This reflects lower imports that businesses rely on as well as more value added supported by those businesses economy-wide.

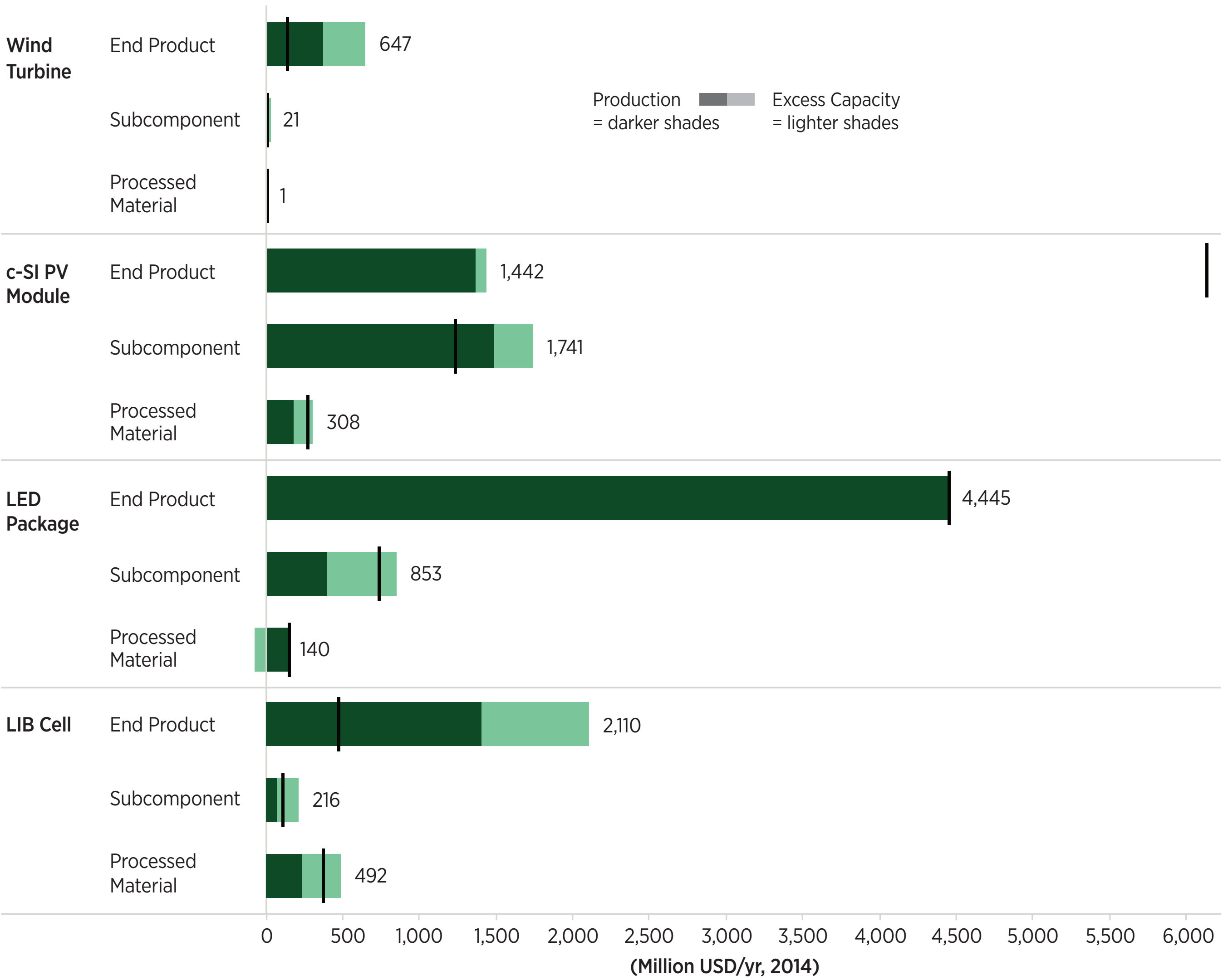


Figure 14-2. Japan's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, across supply chain, 2014 (for LED packages, assumed production equal to demand due to lack of demand data). See methodology report for data quality discussion.

42. OECD STAN database (2015)

Manufacturing Landscape: Demand, Manufacturing Capacity and Production

Japan's manufacturing sector accounted for 18.5% of Japan's GDP in 2014 (McKinsey Global Institute 2015). Consumer electronics and automobiles dominate Japan's manufacturing sector. Japan is the third largest manufacturer of automobiles and is home to 7 of the top 20 chip manufacturers. Manufacturing as a share of GDP peaked in 1984 at 29%. Since then, Japan's manufacturing sector has declined due to increased domestic production capacity in other Asian economies and offshoring of production to reduce costs.

In 2014, Japan was the global leader in LDV Li-ion cell manufacturing and home to a strong manufacturing base for LED packages and c-Si PV modules across the supply chain. Figure 14-2 shows Japan's 2014 manufacturing capacity, production, and demand for the four technologies included in this analysis.

Along the c-Si PV module supply chain, Japan hosted the third-largest share of module, cell, and wafer capacity, and the fifth largest share of polysilicon manufacturing capacity of the economies listed in this report. For LDV Li-ion batteries, Japan hosted the second-largest share of capacity in cell (25%), cathode and anode (30%), and separator manufacturing (22%), and the largest share of electrolyte manufacturing capacity (30%). In 2014, Japan hosted LED package annual manufacturing capacity totaling 47.8 billion packages, the largest single economy share of capacity globally (30%). Japan was also home to 12% of global manufacturing capacity for LED chips, and 10% of global capacity for sapphire substrate, the fourth-largest shares of total global capacity for each of these intermediate products.

Relative to other economies within each technology sector, Japan utilized as much as or more of its manufacturing capacity in the four selected clean energy technologies. Japan's PV module manufacturers achieved an average utilization rate of 95%, while Japanese Li-ion cell manufacturers averaged 67%. These rates are well above global averages of 55% and 41% for PV modules and Li-ion cells, respectively. This is potentially indicative of a more conservative approach taken by Japanese firms in serving high growth markets, as manufacturing capacity build-out has occurred in closer balance with demand growth.

On the demand side:

- Japanese demand for PV modules totaled 8,600 MW in 2014 (22% of the total global market), making it the second-largest single economy demand market in that year behind China. An early pioneer in PV, Japan's PV manufacturing base was initially driven by government incentives and global demand.
- Japanese LDV Li-ion cell demand was 1,300 MWh in 2014, making it the second-largest demand market behind the United States. The market was driven by Japan's well-developed electrified vehicle manufacturing base and also by strong domestic consumer demand for electrified vehicles.
- Japanese demand for lighting-specific LED packages totaled 47.8 billion packages in 2014 (30% of total global demand), making it the largest single-economy demand market in that year. Japan's LED-related manufacturing base is an outgrowth of its strong relative position in the general semiconductor manufacturing sector.
- Japan constituted a relatively small demand market for wind turbine components in 2014, as a result of minimal available land area, and a challenging marine environment. Demand for wind turbines was 130 MW.

Trade Landscape: Balance of Trade and Trade Flows

Japan maintains an open, transparent economy and participates in a network of 13 regional trade agreements. In the clean energy sector, Japan does not impose any local content policies or import tariffs on wind or solar. There are a variety of nontariff barriers in the automotive industry, such as standards and certification. However, there are no direct limits for Li-ion components or cells. (WTO 2015b)

In Figures 14-3 through 14-7, we present the balance of trade and trade flows for the supply chain links for which trade data are available. In 2014 Japan held a positive balance of trade in LED packages and cells (2.6 billion USD) and Li-ion batteries (1.5 billion USD) and a negative balance in PV (-7.5 billion USD) and wind generator sets (-84 million USD). By comparison, in 2014 Japan maintained an 84.4 billion USD positive balance of payments, which includes both traded goods and services.

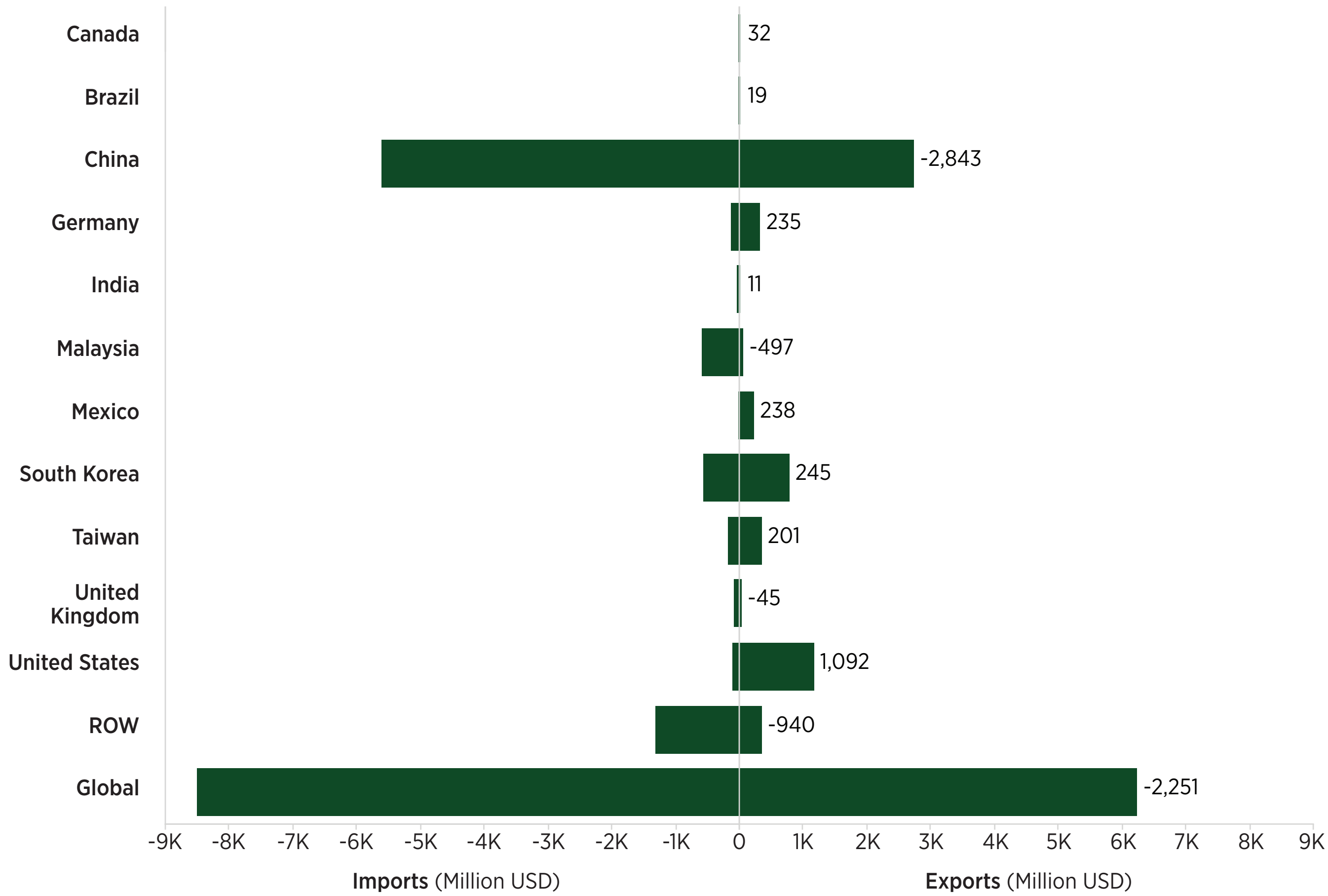


Figure 14-3. Japan's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

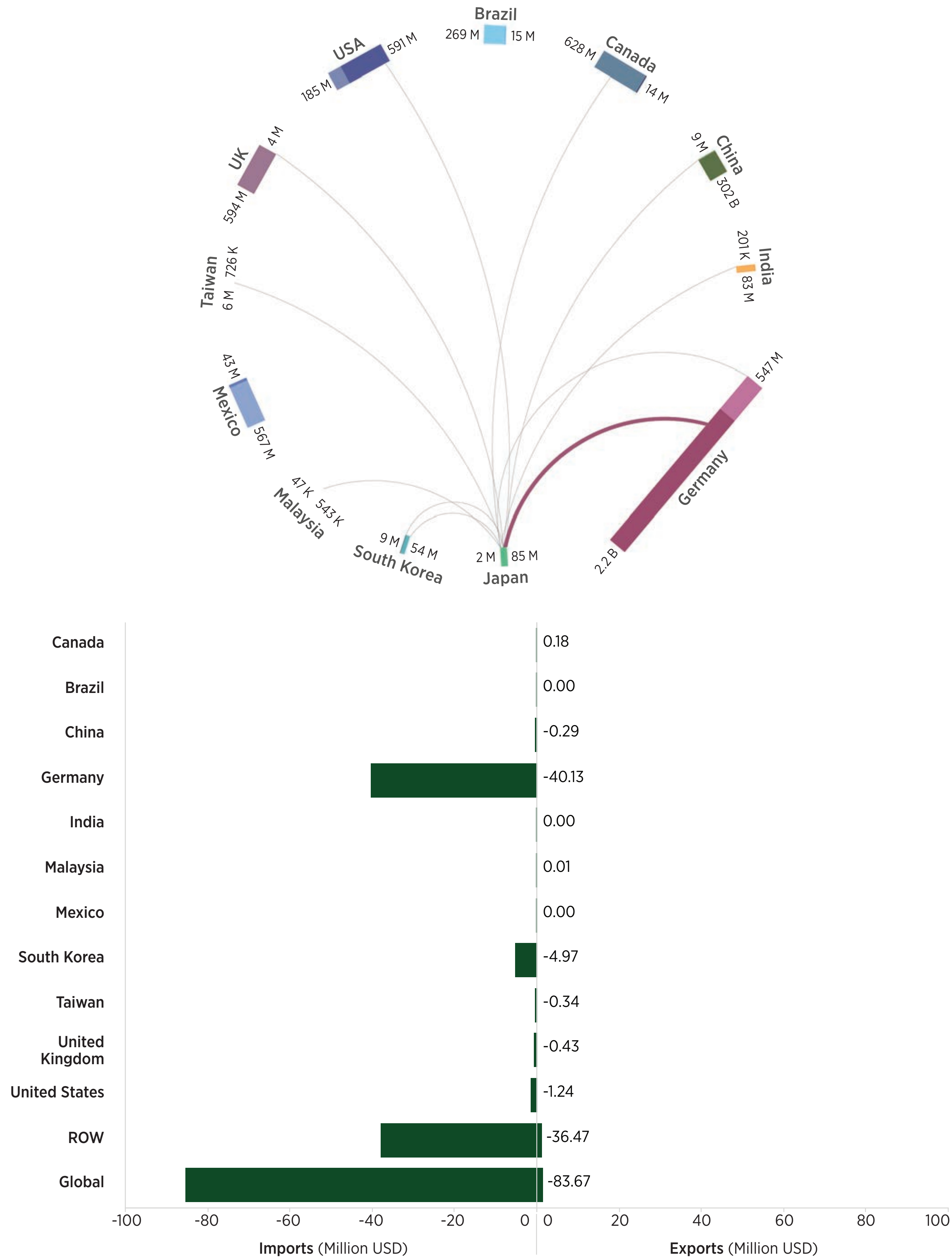
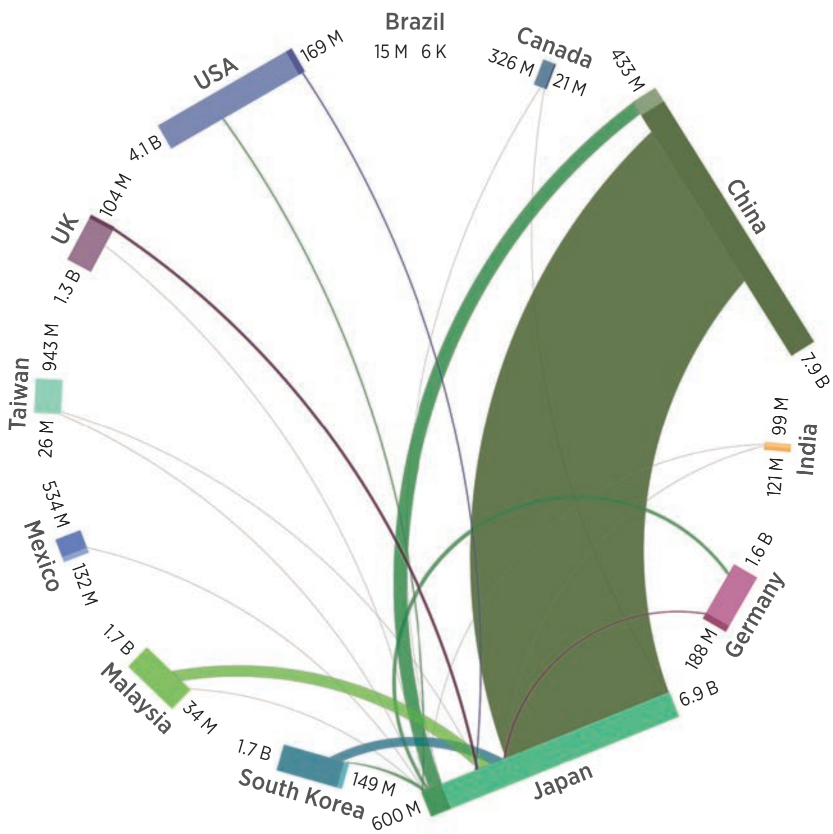


Figure 14-4. Trade between Japan and key partners in wind turbine generator sets, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



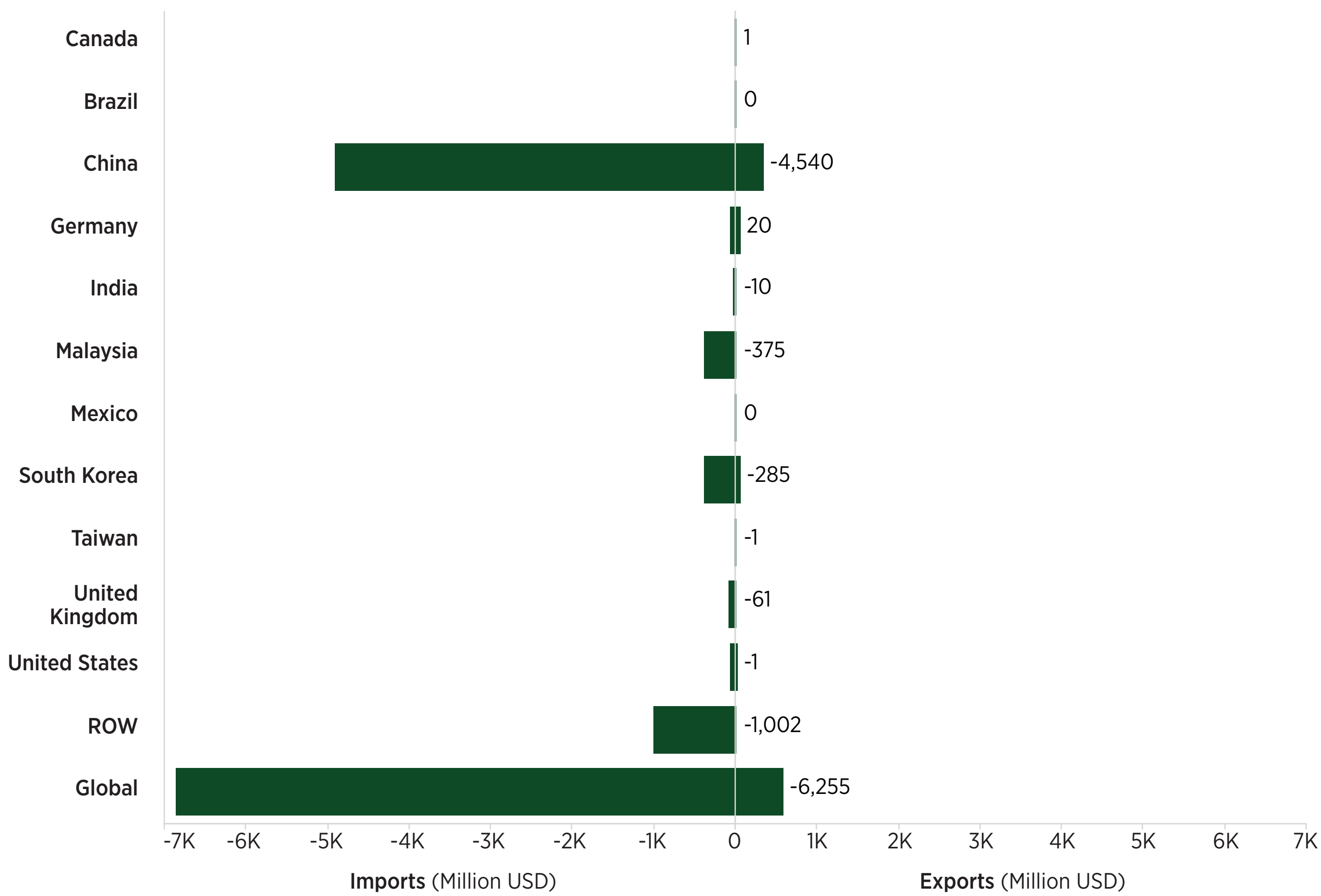


Figure 14-5. Trade between Japan and key partners in c-SI PV modules, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

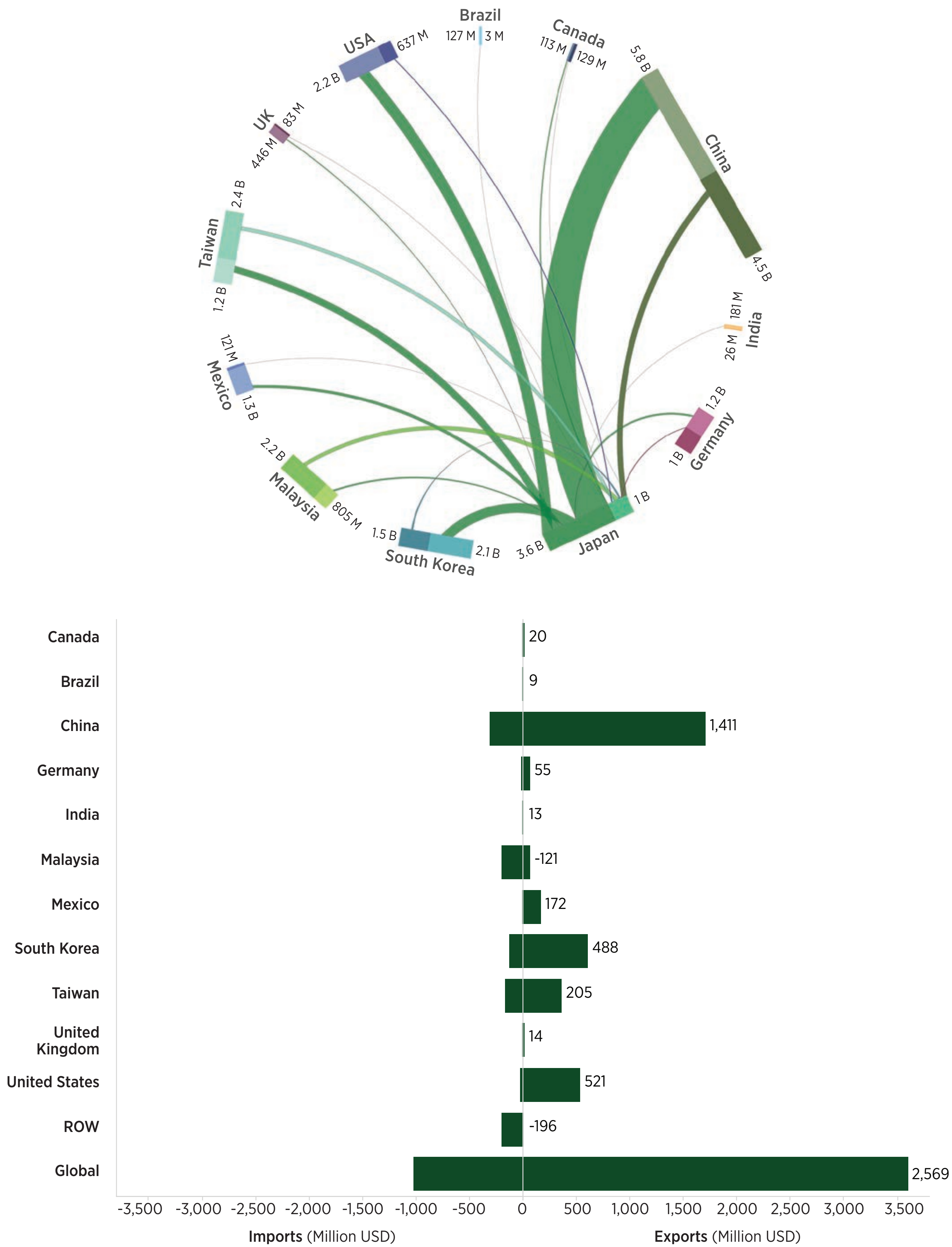
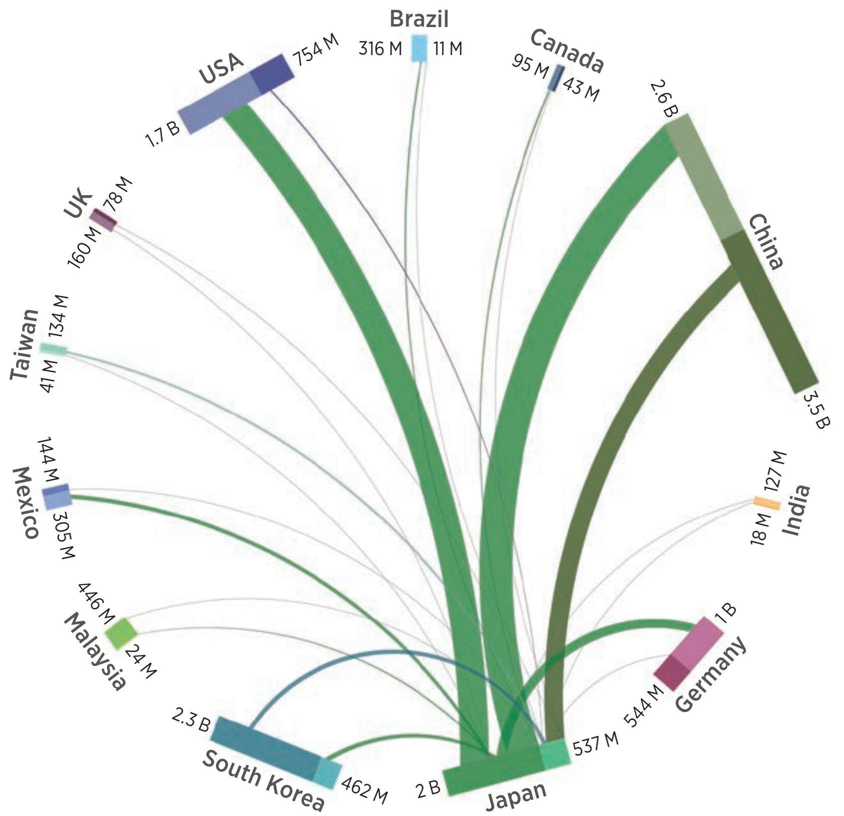


Figure 14-6. Trade between Japan and key partners in LED packages, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



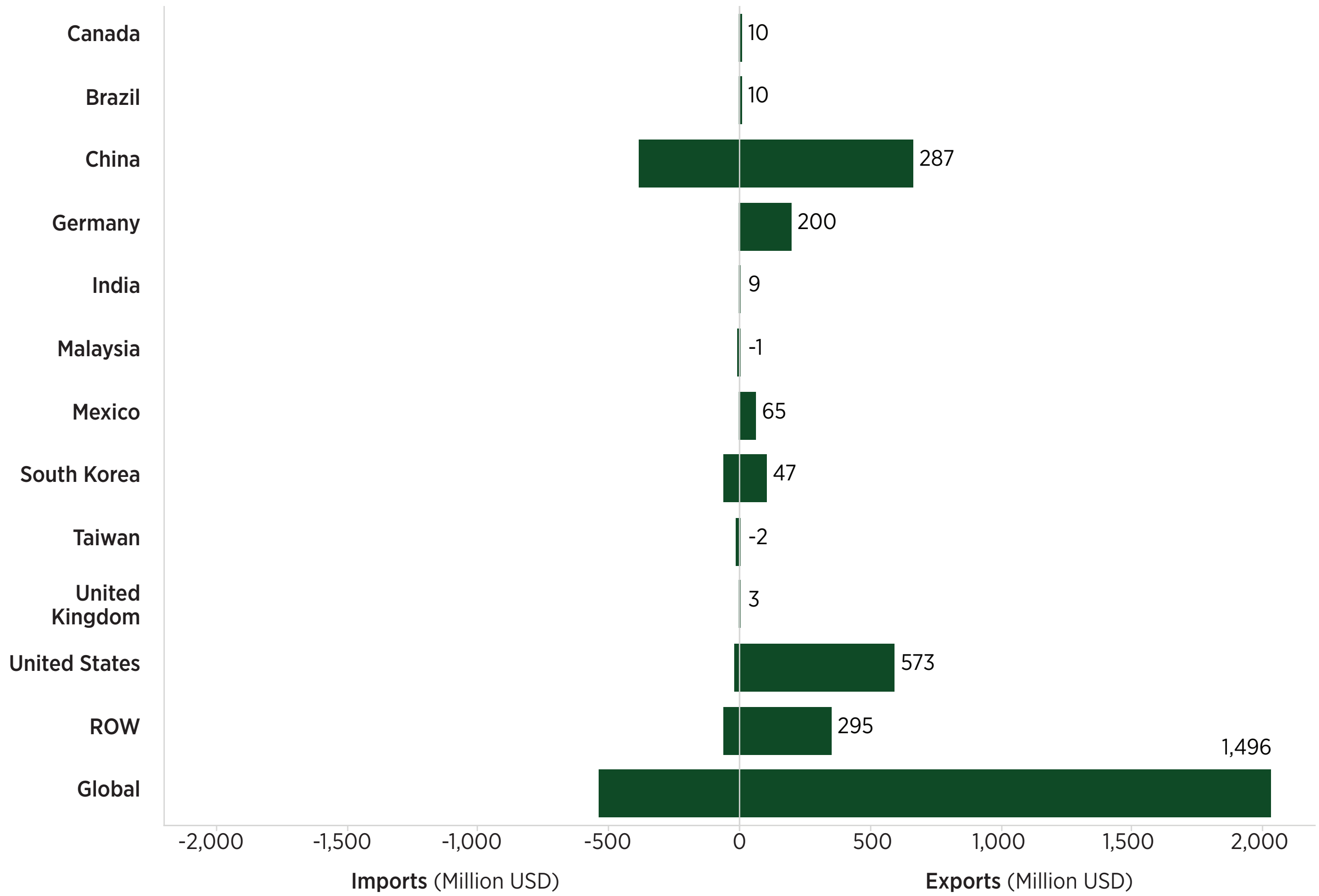


Figure 14-7. Trade between Japan and key partners in Li-ion cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

15 | Malaysia: Clean Energy Manufacturing Profile

Malaysia is a small economy—gross domestic product was 338 billion USD in 2014—that focuses on light manufacturing for economic growth and trades predominantly with other economies in the Asia-Pacific region. Malaysia has been experiencing relatively stable and high growth rates of just under 6% for the last several years. One result of this growth is increased domestic demand for energy. Today, Malaysia has roughly 31 GW of installed generating capacity. Much of the recent investment in energy infrastructure has been in clean energy, particularly biofuels. Malaysia had a cumulative 160 MW of PV generation installed in 2014 (IRENA 2015a). There are few policies that promote clean energy manufacturing in Malaysia, but the sector has grown regardless. This growth is in part due to increased demand abroad. For example, Malaysian manufacturers assemble inexpensive Chinese PV module components into modules. The modules are largely for export. Malaysia's domestic PV demand is small, but growing due to policies like feed-in-tariffs for solar power.

Key Findings

- In 2014, manufacturing of PV module components and LED packages contributed 1.3 billion USD in combined direct and indirect value added to Malaysia's economy. The highest levels of value added supported by clean energy manufacturing technologies was 639 million USD from LEDs and 632 million USD from c-Si PV modules.
- In the selected clean energy technology sectors covered in this analysis, Malaysia's manufacturing utilization rates are generally at or above global averages. Malaysia's PV module manufacturers achieved an average utilization rate of 60%, above the global average of 55%.
- For the four technologies considered, in 2014, exports totaled 4.9 billion USD and imports totaled 1.1 billion USD, leaving Malaysia with an overall positive balance of trade (3.8 billion USD).[43] The top trading partners with Malaysia were Japan, China, and Taiwan. Among clean energy manufacturing products, Malaysia exported the most PV modules and cells as well as LEDs while importing the most LEDs.

Economy

- GDP (nominal USD, 2014): 338 billion (World Bank 2016)
- Economy-wide value added contribution (% of gross output, 2014): 34%
- Import contribution (% of gross output, 2014): 20%
- GDP growth rate (five year average 2010–2014): 5.8% (World Bank 2016)
- Manufacturing, value added (% of GDP, 2013): 22.8%
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.4

Trade

- Total imports (USD, 2014): 234 billion (WITS)
- Total exports (USD, 2014): 209 billion (WITS)
- Main trading partners (2014): Singapore, China (exports)
- Main trading partners: China, Singapore (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 31 GW (Suruhanjaya Tenaga Energy Commission 2016)
- Renewable share (excluding large hydro): 4.3%
- Total investment in clean energy (USD, 2014): 44 million (BNEF 2016)

RE and EE Targets

- 11% of electricity generation by 2020
- 17% of electricity generation by 2030
- 6% reduction in demand by 2024 (Proposed) (Mekhilef et al. 2014)

43. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 4.6 billion USD in revenue from manufacturing of PV modules and LED packages supported 1.3 billion USD of value added (732 million USD direct, 539 million USD indirect) in Malaysia (Figure 15-1). Across the technology supply chains, the highest total value added came from LED packages (639 million USD), and PV modules (632 million USD).[44]

Both PV module and LED package manufacturing in Malaysia generated more direct than indirect value added, highlighting the relative significance of the manufacturers themselves compared to their greater supply chains within Malaysia.

Clean energy manufacturers in Malaysia retained relatively low portions of direct value added compared to other economies—16% for Malaysia and 25% for the 12-economy

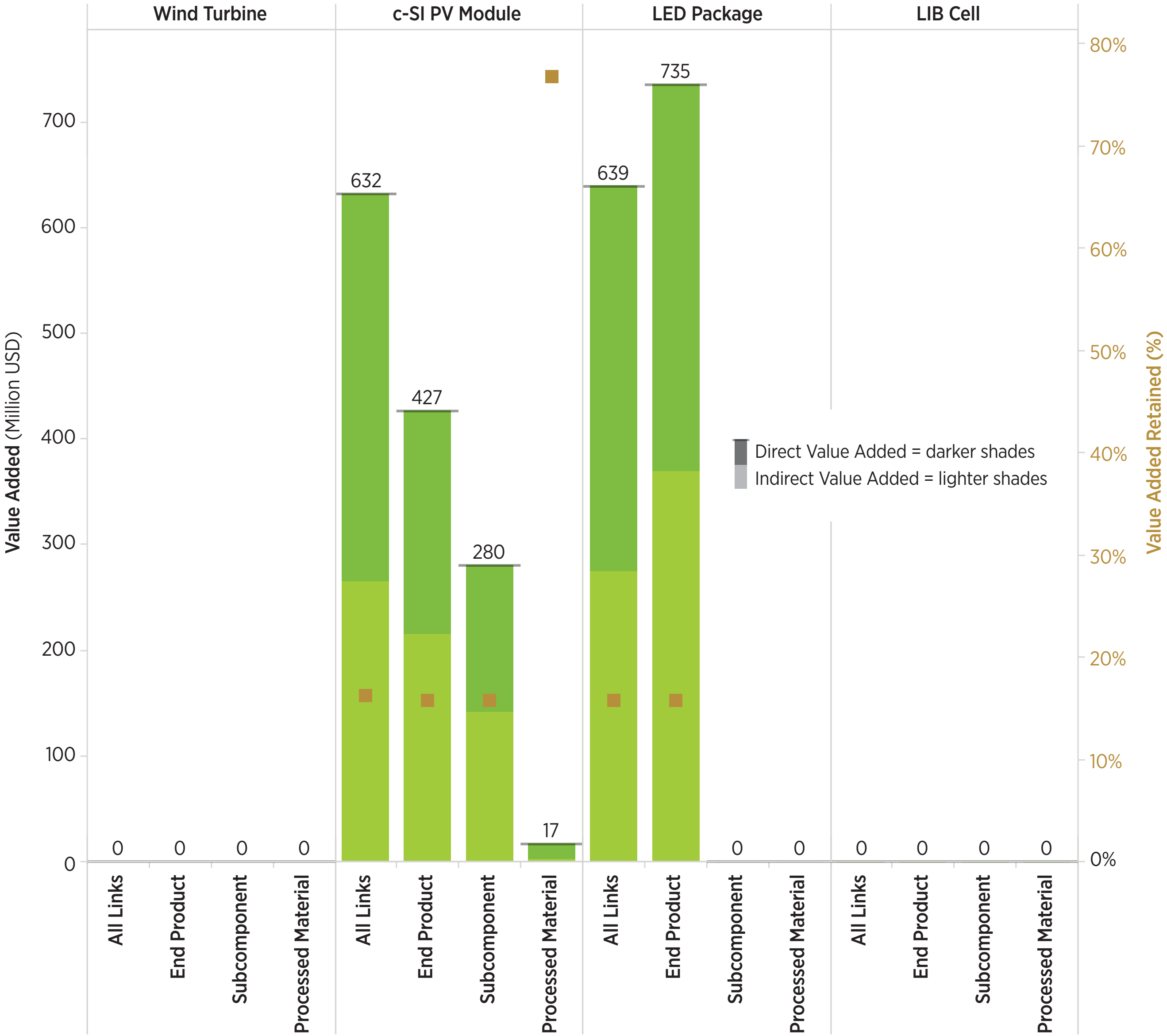


Figure 15-1. Malaysia's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

44. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

average. This is consistent across the four selected clean energy technologies individually as well as in total.

Malaysia trails all considered economies in direct and indirect value added retained. Clean energy manufacturers and their greater supply chains retain 28% of total value added compared to an average of 55% across all economies in this report and technologies.

The relatively smaller economy-wide , direct, and indirect impacts of clean energy manufacturing are driven by characteristics of Malaysia's economy, including relatively high import numbers and low value added. Malaysia is tied with Taiwan for the highest level of imports as a percentage of gross output, a metric indicative of less well-developed domestic supply chains. Less developed domestic supply chains mean that manufacturers rely more on imports. Malaysia had the second lowest contribution of value added to gross output of the 12 economies considered. The portion of Malaysian revenue that leaves the economy to pay for imported inputs is 20%, compared to the 12-economy average of 11%. Value added across all industries as a portion of revenue economy-wide is 34%, less than the 46% average.[45]

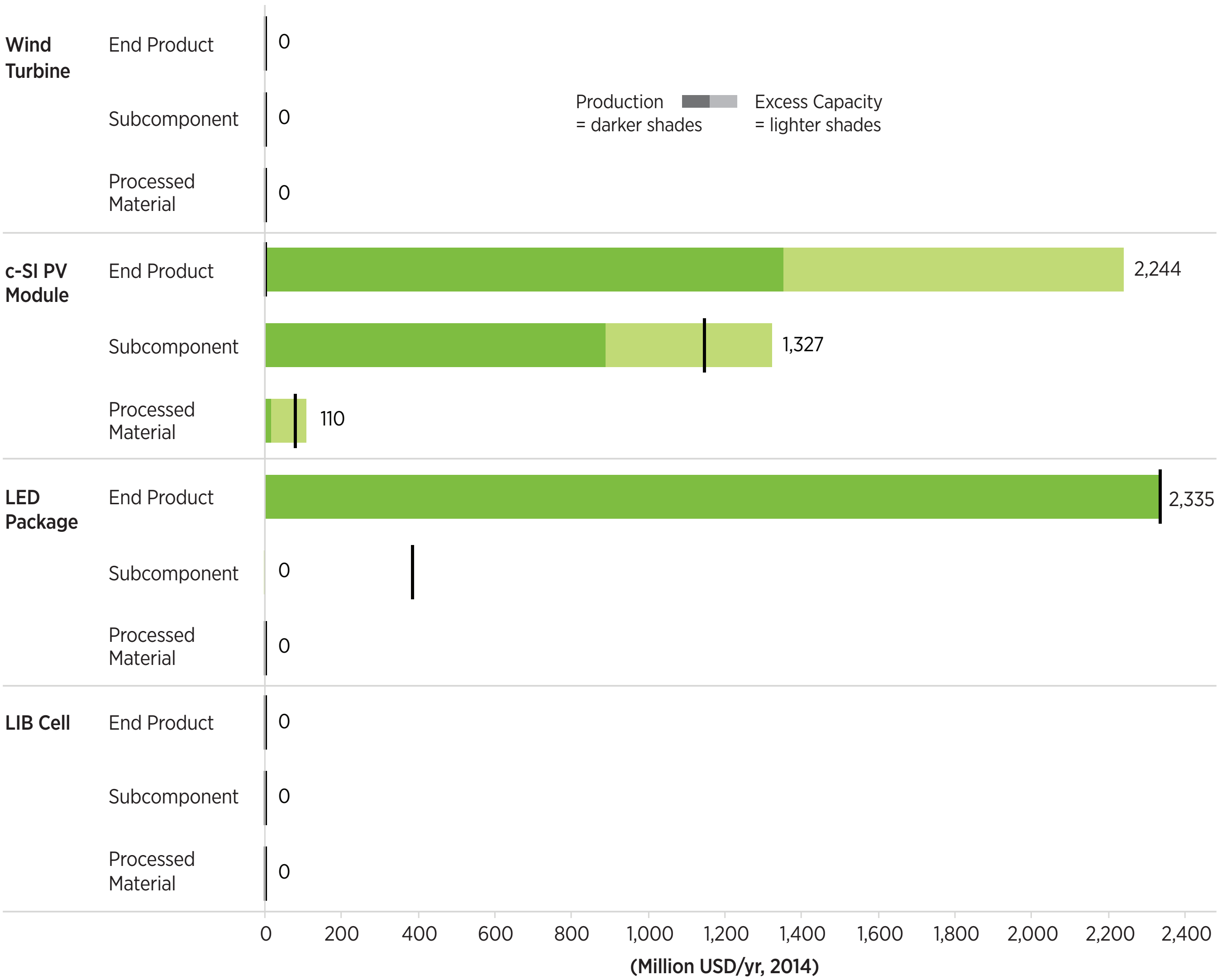


Figure 15-2. Malaysia's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies (for LED packages, assumed production equal to demand due to lack of demand data), 2014. See methodology report for data quality discussion.

45. OECD STAN database (2015)

Manufacturing Landscape: Demand, Manufacturing Capacity and Production

Malaysia's manufacturing sector is an important contributor to the county's economy, contributing 22.8% (77 million USD) to the GDP in 2014. Malaysia has enacted a number of policies and incentives that have helped make Malaysia a desirable location to build manufacturing capacity for clean technologies.

Malaysia's Green Energy Finance Scheme, which began in 2010, provides up to 12 million USD in "soft" loans for manufacturing clean technologies, and up to 2.5 million USD for users of the renewable energies (IEA 2010). This policy promotes domestic manufacturing of clean energy because the companies must be at least 51% Malaysian owned in order to qualify for the scheme. The Malaysian government has also adopted policies that aim to boost its LED manufacturing sector. The Green LED program is designed to keep Malaysian companies up to date on manufacturing technologies. It gives funding for the development of LED products, as well as full and partial grants for purchasing or improving LED manufacturing equipment to bolster LED manufacturing capacity (SME Corporation Malaysia 2016). The Malaysian government has also offered incentives for the domestic assembly or manufacture of hybrid-electric and battery-electric vehicles and components (OECD 2015a).

Malaysia has recently grown to be a significant PV manufacturing center, and is the second-largest PV module producer behind China. In 2014, Malaysia's PV manufacturing capacity included 3,200 MW of module capacity (4% share of the global total), 2,900 MW of cell (4% share), 1,100 MW of wafer (2% share), and 1,200 MW of polysilicon (2% share). Malaysian production in the same year totaled 1,900 MW of modules and cells, 800 MW of wafers, and 210 MW of polysilicon. All 1,900 MW of PV modules produced in 2014 were exported. Many manufacturing facilities located in Malaysia are owned by foreign companies headquartered in China, Japan, Korea, and the United States. Recent Chinese manufacturing expansions into Malaysia may be driven in part by import tariffs or other barriers placed on Chinese modules and cells by the United States and the European Union.

Malaysia was also home to a significant amount of LED package manufacturing capacity, with 2014 capacity estimated at 25 billion packages per year, constituting 15% of global capacity. Malaysia did not host any LED chip or sapphire substrate capacity in 2014.

Malaysia did not host any wind- or LDV Li-ion battery-related manufacturing capacity in 2014.

Malaysia manufacturing utilization rates are generally at or above global averages. Malaysia's PV module manufacturers achieved an average utilization rate of 60%, above the global average of 55%.

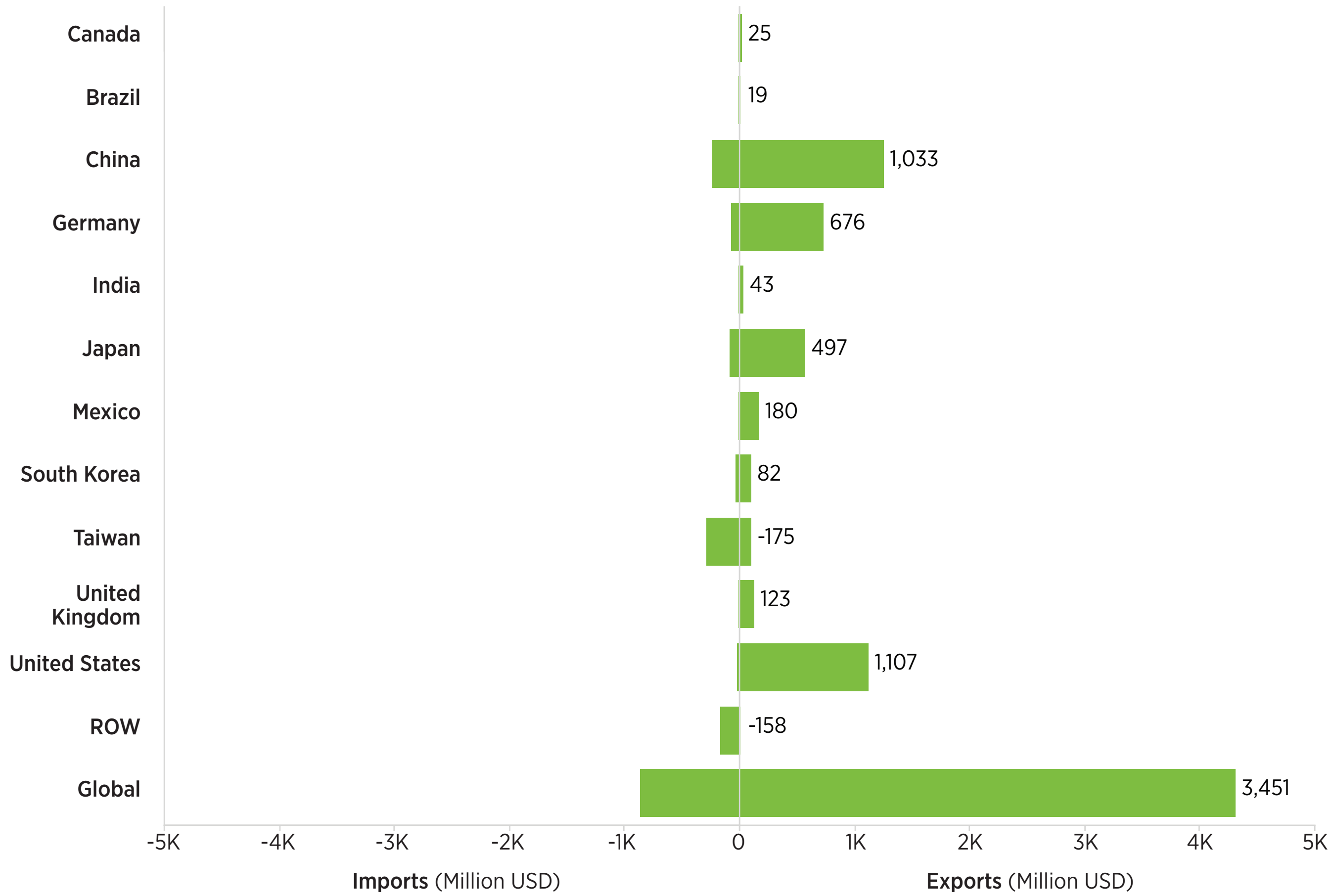
Regarding demand for clean energy technologies:

- Malaysia did not have any domestic demand for wind turbine components in 2014.
- In 2014, Malaysia had no significant domestic demand for c-Si PV modules; all modules produced were exported.

Trade Landscape: Balance of Trade and Trade Flows

Malaysia's economy is strongly dependent on imports and exports, and a considerable proportion of its trade activities occur within the Asia-Pacific region. According to the WTO, Malaysia's trade policy is focused on ensuring that Malaysia becomes a self-reliant and industrialized nation by 2020. Emphasis is being placed on integrating Malaysian companies into global supply chains and developing commercial ties with new markets (WTO 2014a).

With respect to clean energy technologies, Malaysia has no trade barriers currently in place, and has no tariffs levied against it from any of its major trading partners. In 2014, India considered including Malaysia in antidumping measures targeting Chinese solar panels. However, those measures ultimately failed to pass through. In addition, Malaysia has been investigated by the WTO for allegations of dumping solar components and panels (Roy and Chaturvedi 2014). Figures 15-3 through 15-7 describe Malaysia's balance of trade in the selected clean energy technologies both collectively and individually.



Figures 15-3. Malaysia's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

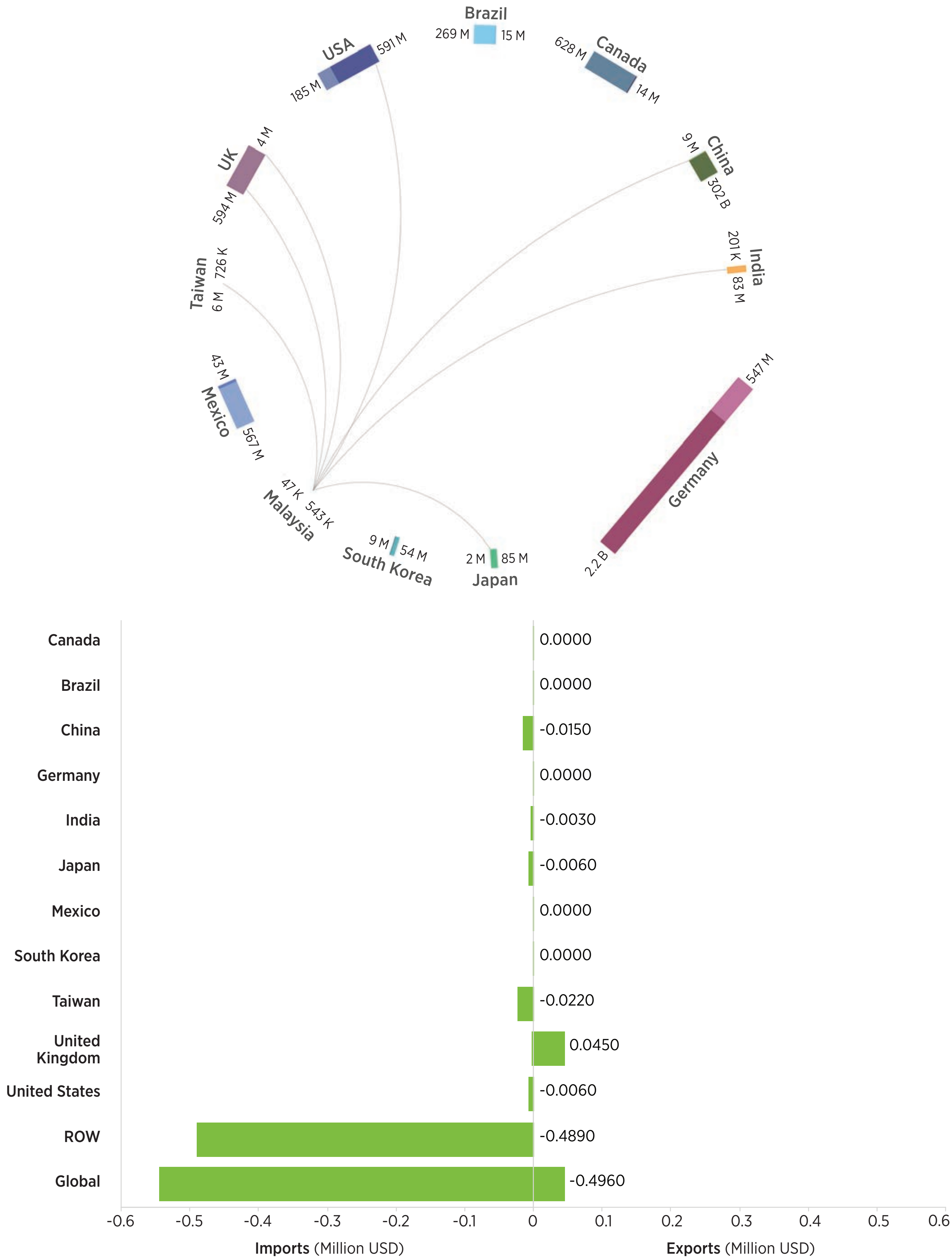


Figure 15-4. Trade between Malaysia and key partners in wind turbine generator sets, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

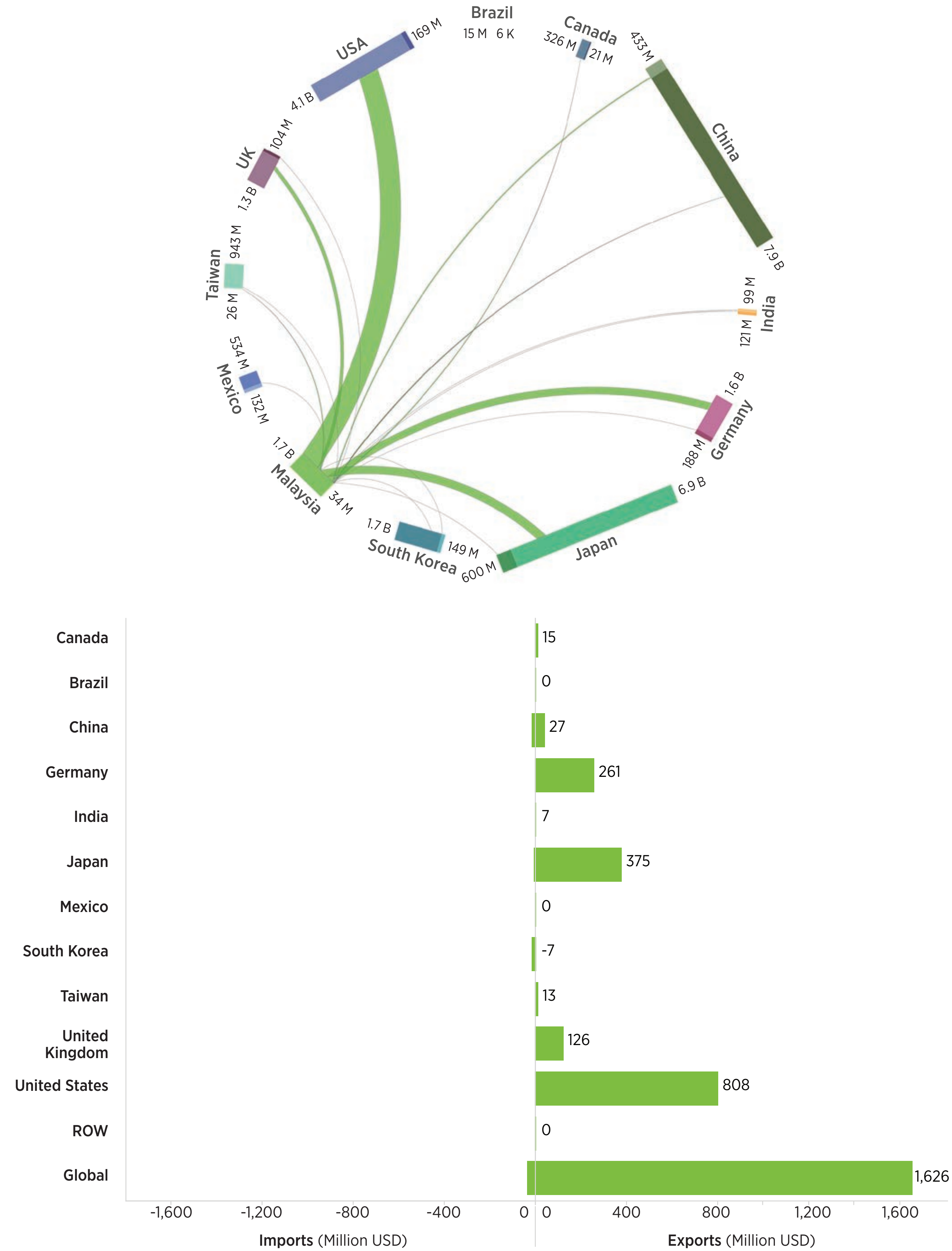


Figure 15-5. Trade between Malaysia and key partners in c-SI PV modules, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

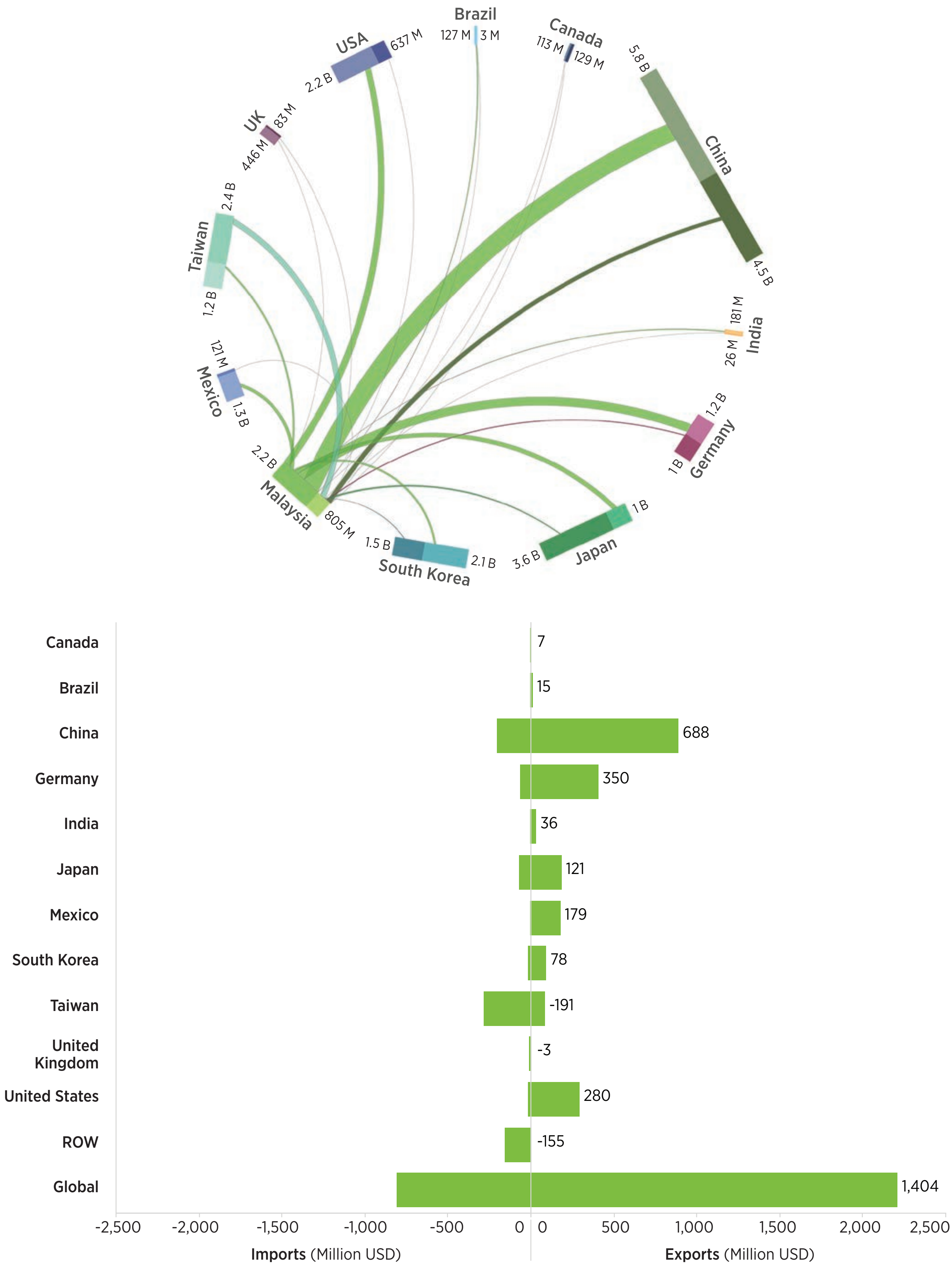


Figure 15-6. Trade between Malaysia and key partners in LED packages, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

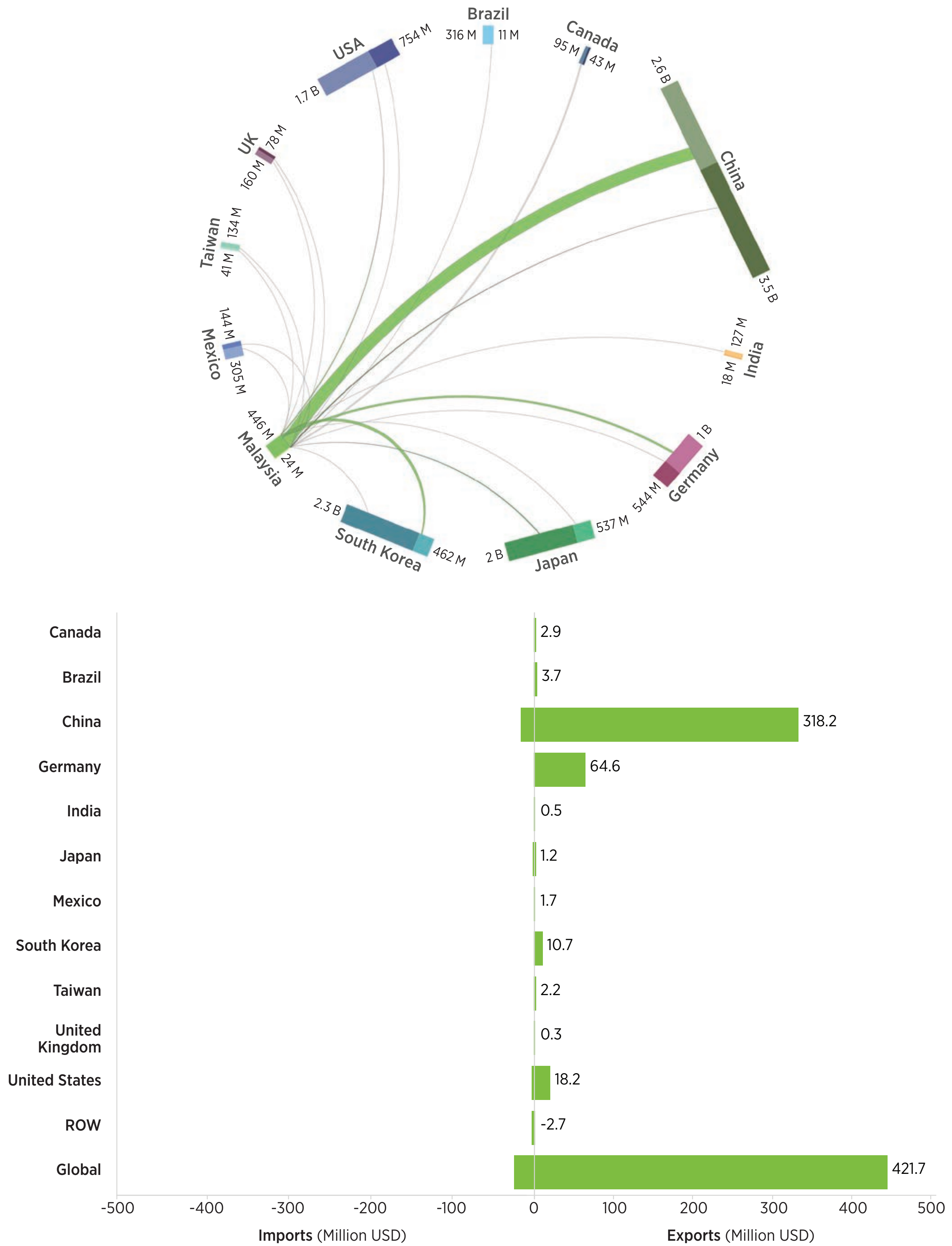


Figure 15-7. Trade between Malaysia and key partners in Li-ion cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

16 | Mexico: Clean Energy Manufacturing Profile

With a GDP of almost 1.3 trillion USD, Mexico's economy is the fifteenth largest in the world. Mexico has had a long history as a major energy producer, but that energy has traditionally been from oil and gas production. Economic growth has resulted in increased energy demand in Mexico, supported primarily through expansion of natural gas and wind energy. As of 2014, Mexico had a cumulative 131 MW of solar and 2.1 GW of wind energy installed (IRENA 2015a), with additional capacity planned for both sources. There are a host of laws, policies, and incentives to boost both demand and supply of renewable energy technologies.

Key Findings

- In 2014, manufacturing of c-Si PV modules and wind turbine towers and blades supported a total of 391 million USD in direct and indirect value added in Mexico. The highest levels of value added supported by the clean energy manufacturing technologies considered in this report were 367 million USD from c-Si PV and 24 million USD from wind.
- Relative to other economies within each technology sector, Mexico manufacturing utilization rates are above global averages. Mexico's PV module manufacturers achieved an average utilization rate of 81%, above the global average of 55%.
- In 2014, exports of the selected four clean energy technologies, totaled 869 million USD and imports totaled 2.4 billion USD, leaving Mexico with an overall negative balance of trade (-1.5 billion USD).[46] The top trading partners with Mexico were the United States, China, and South Korea. Among clean energy manufacturing products, Mexico exported the most PV modules and cells while importing the most LEDs.

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 1.0 billion USD in revenue from manufacturing of c-Si PV modules and wind turbine components supported 391 million USD of value added (148 million USD direct and 243 million USD indirect) in Mexico (Figure 16-1). Across the technology supply chains, the highest total value added came from c-Si PV modules (367 million USD), and wind turbines (24 million USD).[47]

Economy

- GDP (nominal USD, 2014): 1,295 billion
- Economy-wide value added contribution: 60% of all economic activity (gross output) in 2014
- Import contribution: 10% of gross output, 2014
- GDP growth rate (five year average 2010–2014): 3.4%
- Manufacturing, value added (% of GDP 2013): 17.6
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.6

Trade

- Total imports (USD, 2014): 397 billion (WITS)
- Total exports (USD, 2014): 400 billion (WITS)
- Main trading partners (2014): United States (exports)
- Main trading partners: United States, China (imports)

Energy Sector

- Total installed generation capacity (2014): 54 GW (EIA Beta 2015b)
- Renewable share (excluding large hydro): 7.7%
- Total investment in clean energy (USD, 2014): 909 million

RE and EE Targets

- 35% of electricity generation by 2024 (IRENA 2015c)

46. Figures are only exports and imports covered by the ITC. For wind these only include generator sets, and battery trade is Li-ion batteries for *all* applications.

47. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

Manufacturing of wind turbine components[48] and c-Si PV modules generated more direct than indirect value added across the supply chain.

Clean energy manufacturers in Mexico retain relatively low portions of direct value added compared to other economies—15% for Mexico and 25% for the 12-economy average. Mexico's c-Si PV module and wind turbine component producers supported 14%, and 37%, respectively, in direct value added as a portion of revenue.

In direct and indirect value added retained, Mexico trails all other considered economies excluding Malaysia. Clean energy manufacturers and their greater supply chains support 38% of total value added as a portion of revenue. For the economy as a whole, Mexico shows high value added as a portion of overall economic activity (gross output).

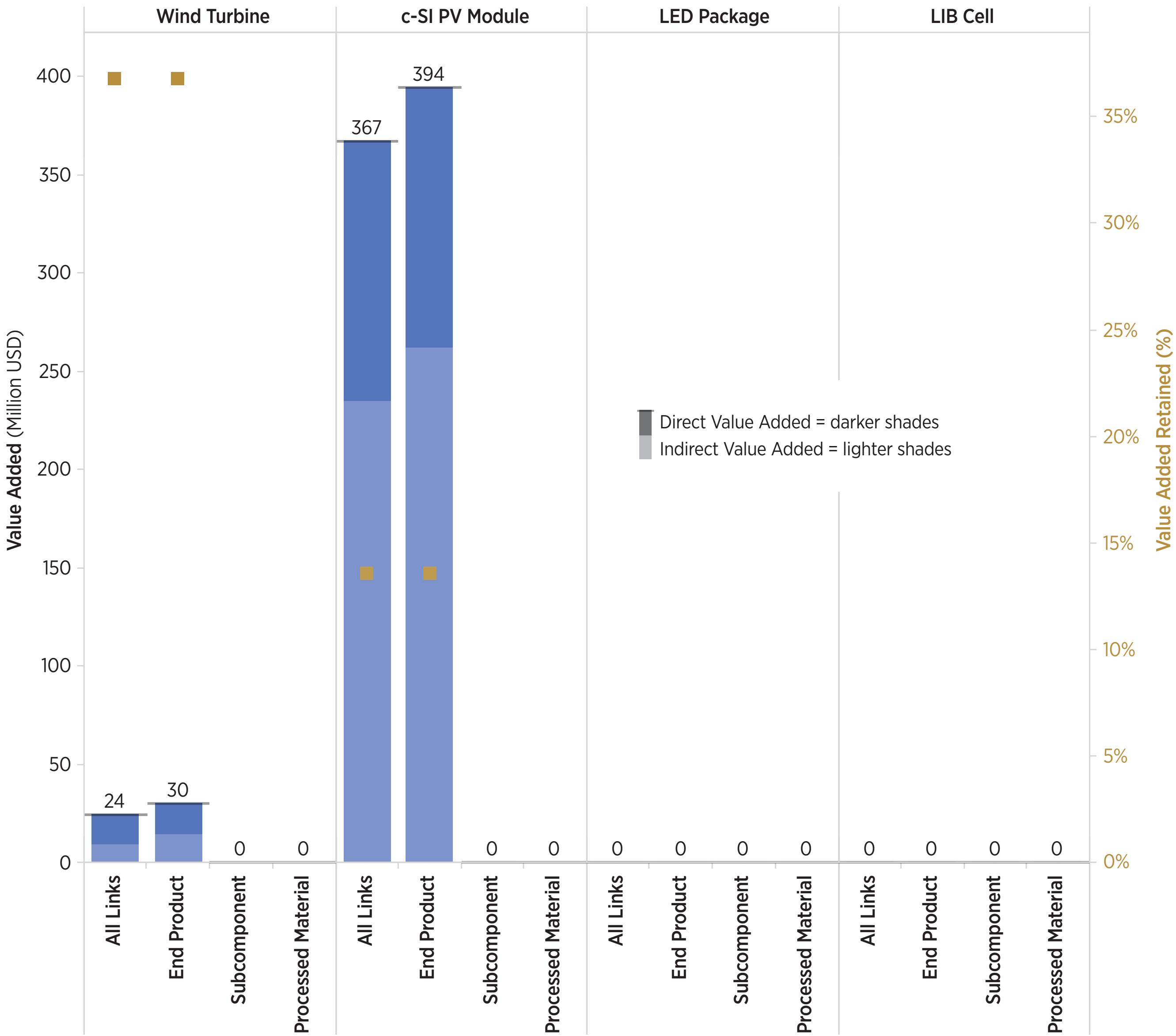


Figure 16-1. Mexico's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

48. Value added from wind blade manufacturing only includes land-based wind.

Value added retained was 60%, the highest level of all economies in this report included in this analysis.[49] However, the industries that support high levels of value added are not a significant part of the clean energy manufacturing supply chain.

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

In 2014 Mexico's manufacturing sector contributed 17.6% to national GDP, equivalent to 226 million USD.

Manufacturing activity in Mexico grew after the signing of the North America Free Trade Agreement (NAFTA) in 1994, particularly in the production of automobiles and auto parts. To boost domestic manufacturing of clean energy components, Mexico provided accelerated depreciation for machinery and equipment for renewable energy generation beginning in 2004. Reforms to the Mexican electricity sector,[50] which open Mexico's energy markets to foreign investment, offer new opportunities for the expansion of renewable energy resources and are expected to drive investment in manufacturing in the

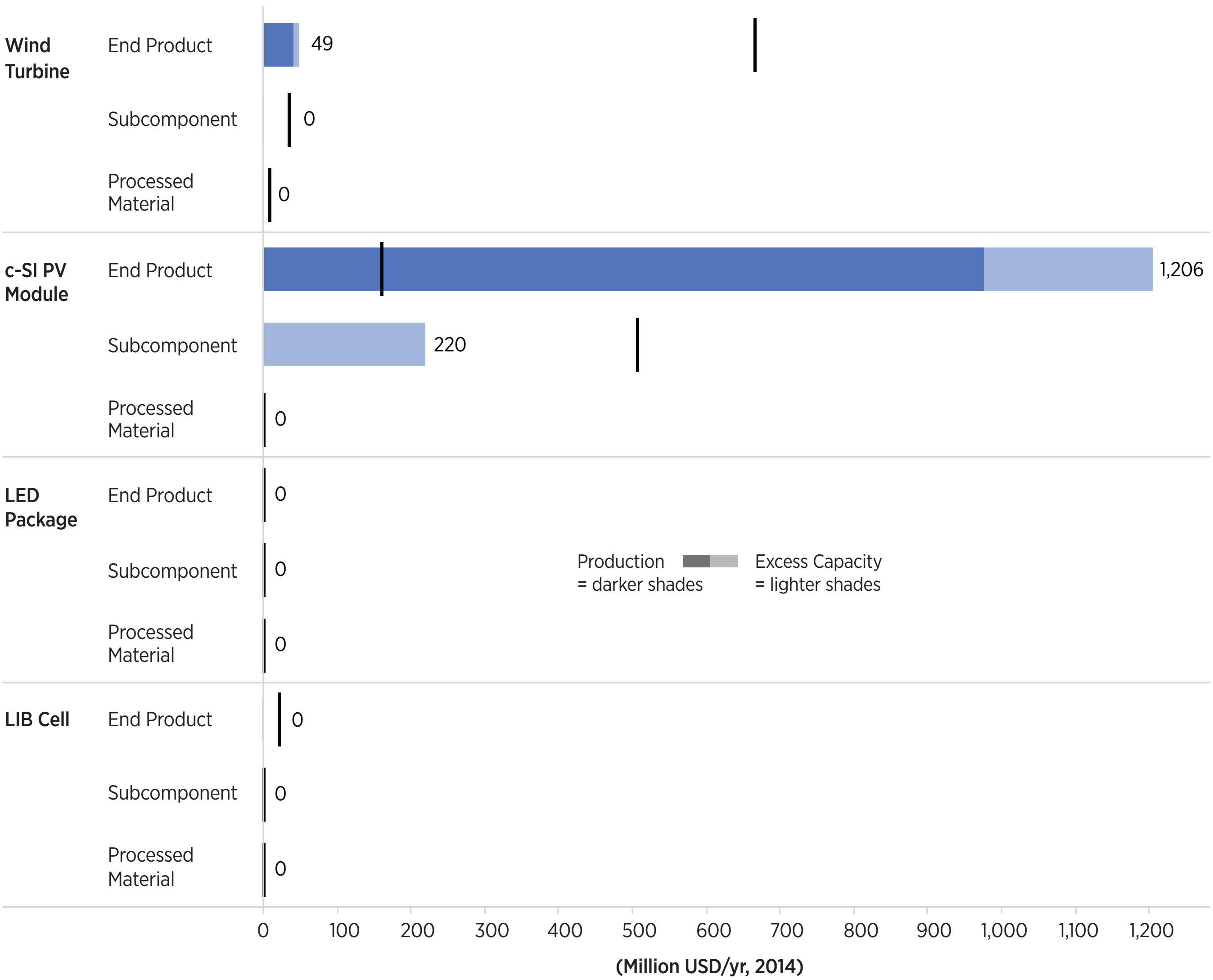


Figure 16-2. Mexico's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, 2014. See methodology report for data quality discussion.

49. OECD STAN database (2015)

50. Mexico's energy sector reform, initiated in 2013, began the process to eliminate state-owned PEMEX's monopoly on exploration, production, and transportation of hydrocarbons to increase (1) oil and gas production and (2) private participation in the electricity sector. https://www.imf.org/external/pubs/ft/wp/2015/wp1545.pdf.

coming years. For example, the Boston Consulting Group estimates that the manufacturing sector could add 20–60 billion USD to Mexico's economy by 2018 (Stratfor 2015).

With respect to clean energy technologies, Mexico has established manufacturing capacity in c-Si PV modules and cells, as well as wind turbine blades and towers. Mexico did not host any LED package or Li-ion battery cell manufacturing in 2014. Figure 16-2 shows Mexico's 2014 demand, manufacturing capacity, and production for PV modules and wind turbines.

Mexico was home to a minor amount of wind tower manufacturing capacity, which totaled 250 MW in 2014, less than 1% of the global total tower manufacturing capacity. Mexico has established a foothold in c-Si PV module manufacturing, and was home to 1,700 MW (2% share) of module manufacturing capacity. Mexico was also host to a minor amount of cell manufacturing capacity, totaling 600 MW (about 1% of total global capacity).

Relative to other economies within each technology sector, Mexico manufacturing utilization rates are above global averages. Mexico's PV module manufacturers achieved an average utilization rate of 81%, above the global average of 55%.

On the demand side:

- Mexico's wind turbine demand was 600 MW in 2014, or 1% of total global demand. Several companies, including Iberdrola, Gamesa, and Acciona, have each announced plans to build additional wind capacity in Mexico before 2018 (ITA 2016).
- Mexico's annual PV module demand totaled 200 MW, less than 1% of the 2014 global total. However, module demand is expected to grow 45% annually between 2015 and 2020, reaching 2,200 MW in annual demand in 2020.
- Mexico had a very minor demand for automotive Li-ion cells, which totaled 100 MWh (1% of total global demand) in 2014.

Trade Landscape: Balance of Trade and Trade Flows

Mexico's trade policy is focused on strengthening and increasing Mexico's participation in world trade through the multilateral trade system and preferential trade agreements. Mexico implemented a trade liberalization program between 2009 and 2013, lowering tariffs on a wide range of manufactured goods. Mexico has also adopted measures to simplify customs procedures and reduce import costs. Mexico promotes its exports through different types of programs, in particular the Program for Industry, Manufacturing, Maquila and Export Services (IMMEX) (WTO 2013). The bulk of Mexico's trade is conducted with partner economies in free trade agreements, particularly the United States through NAFTA. (WTO 2013)

Mexico's main trading partners in clean energy components and end products are the United States and China. Overall, Mexico maintained a balance of trade deficit in the benchmarked clean energy technologies in 2014. Domestic manufacturing may increase due to Mexican policies promoting clean energy development. C-Si PV modules are the only one of the four selected clean energy technologies evaluated in this report in which Mexico has a positive balance of trade. Figures 16-3 through 16-7 show Mexico's balance of trade in the selected clean energy technologies both collectively and individually.

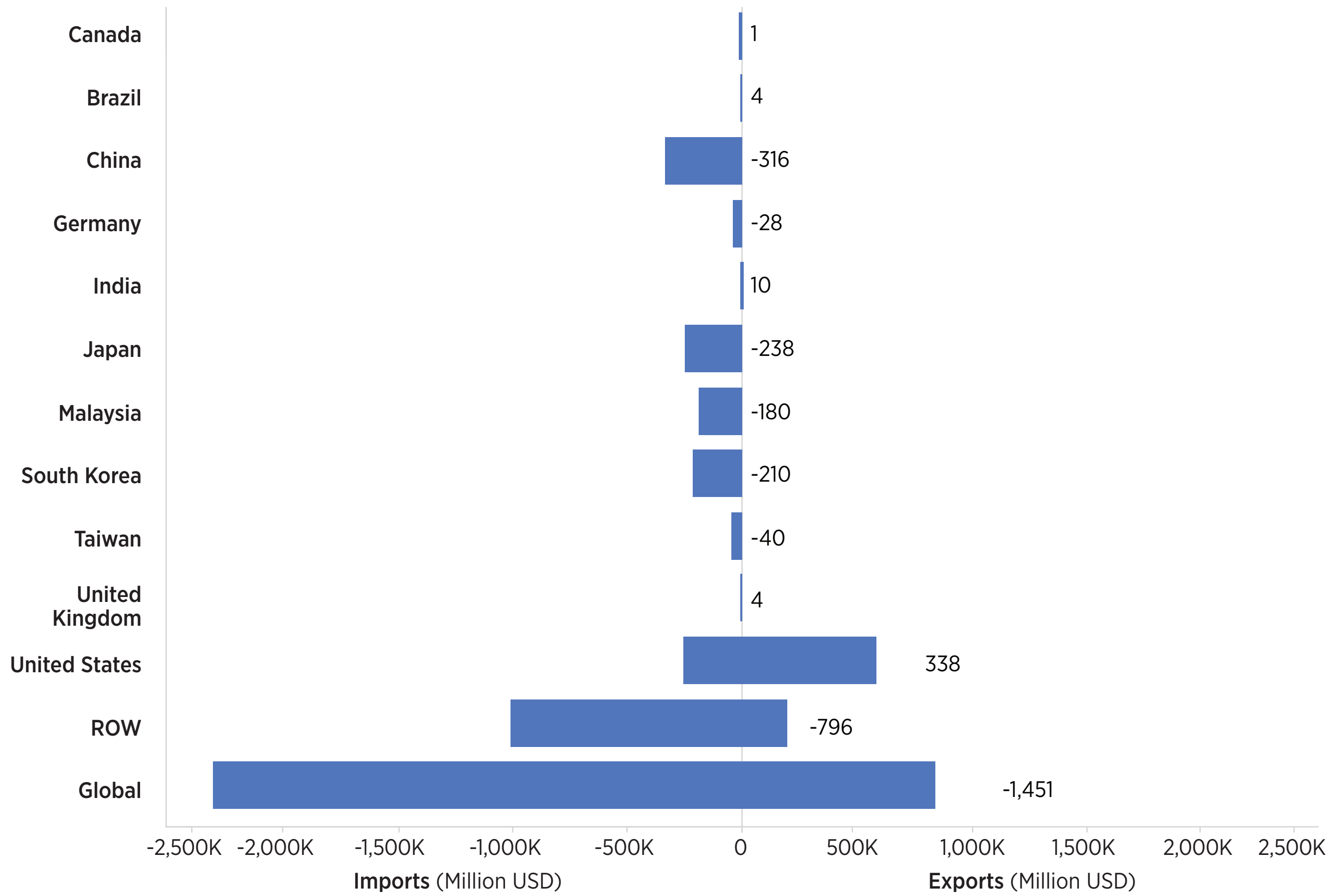


Figure 16-3. Mexico's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

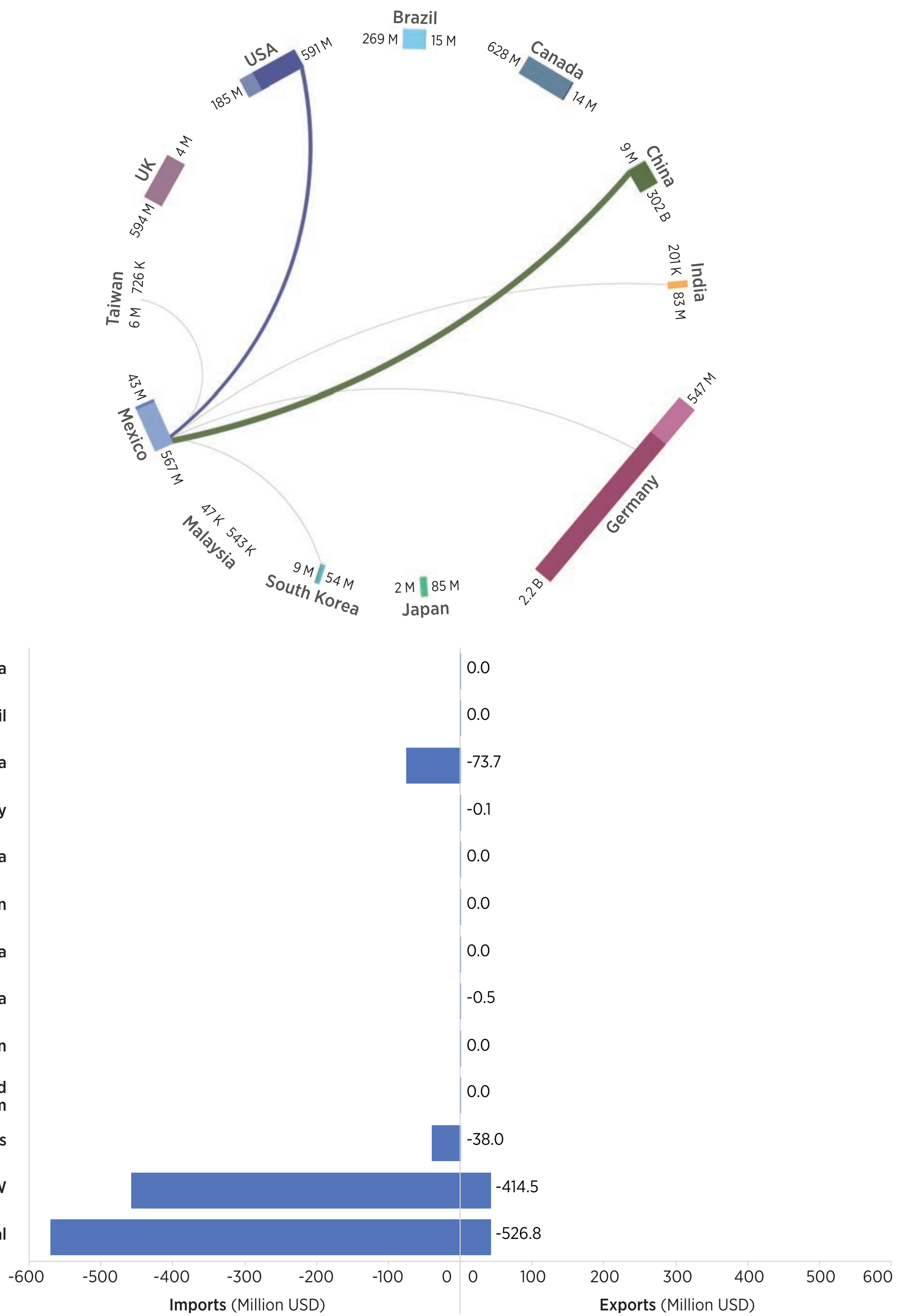


Figure 16-4. Mexico's 2014 Trade Flows and Balance of Trade for Wind Turbine Generator Sets (proxy for nacelles). See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

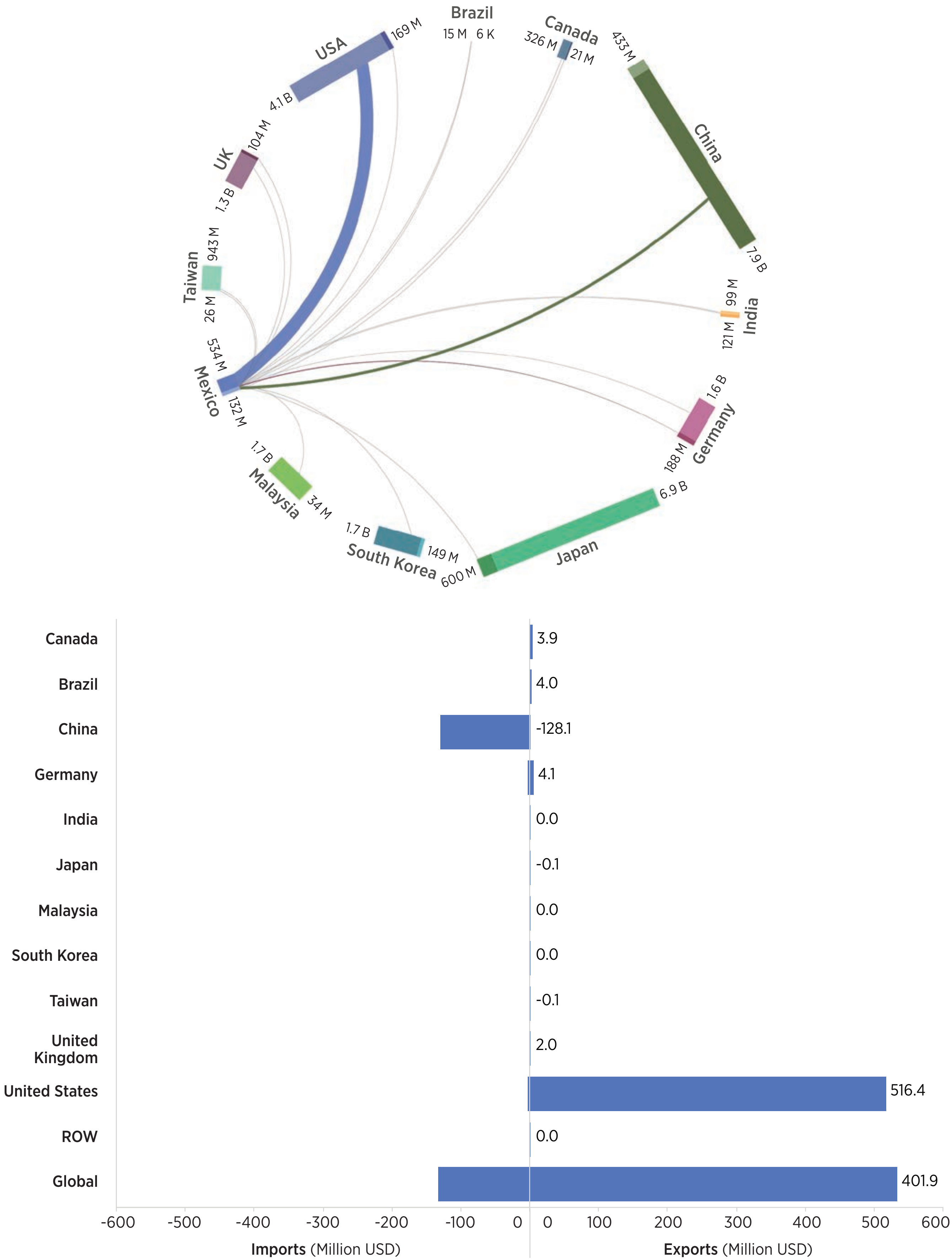
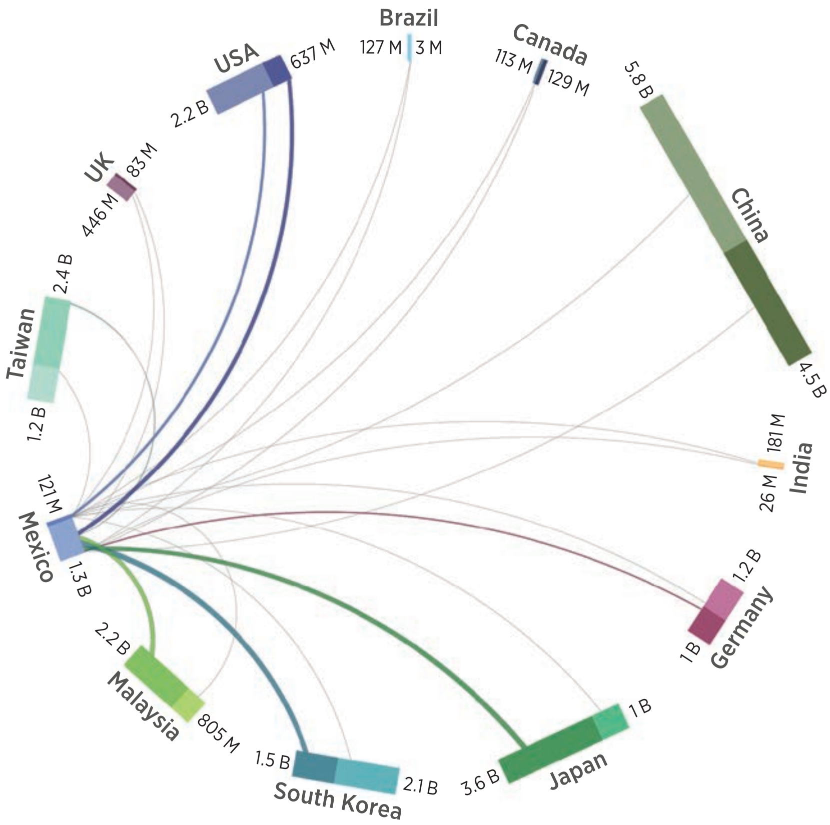


Figure 16-5. Mexico's 2014 Trade Flows and Balance of Trade for PV Modules. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



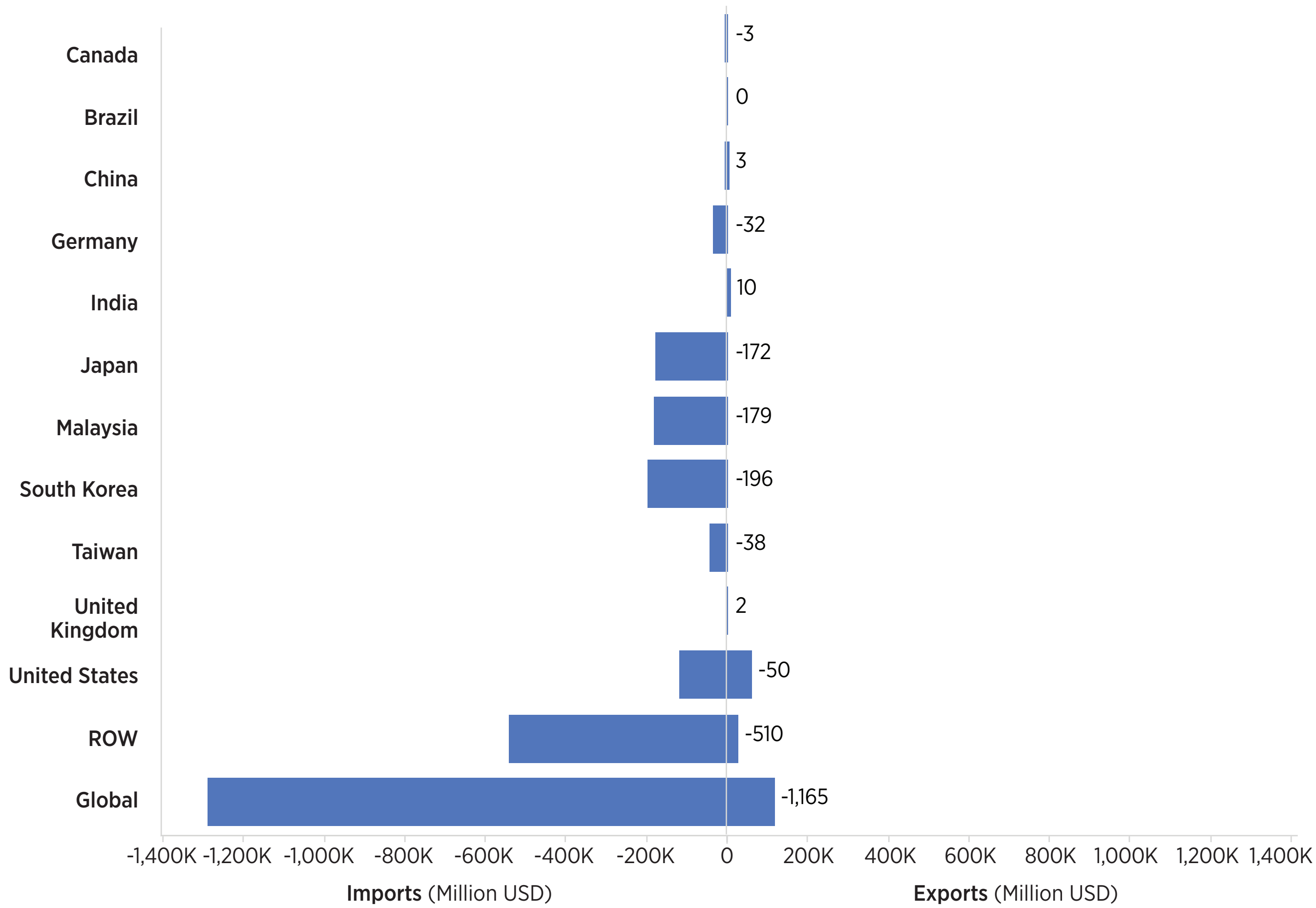


Figure 16-6. Mexico's 2014 Trade Flows and Balance of Trade for LED Packages. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

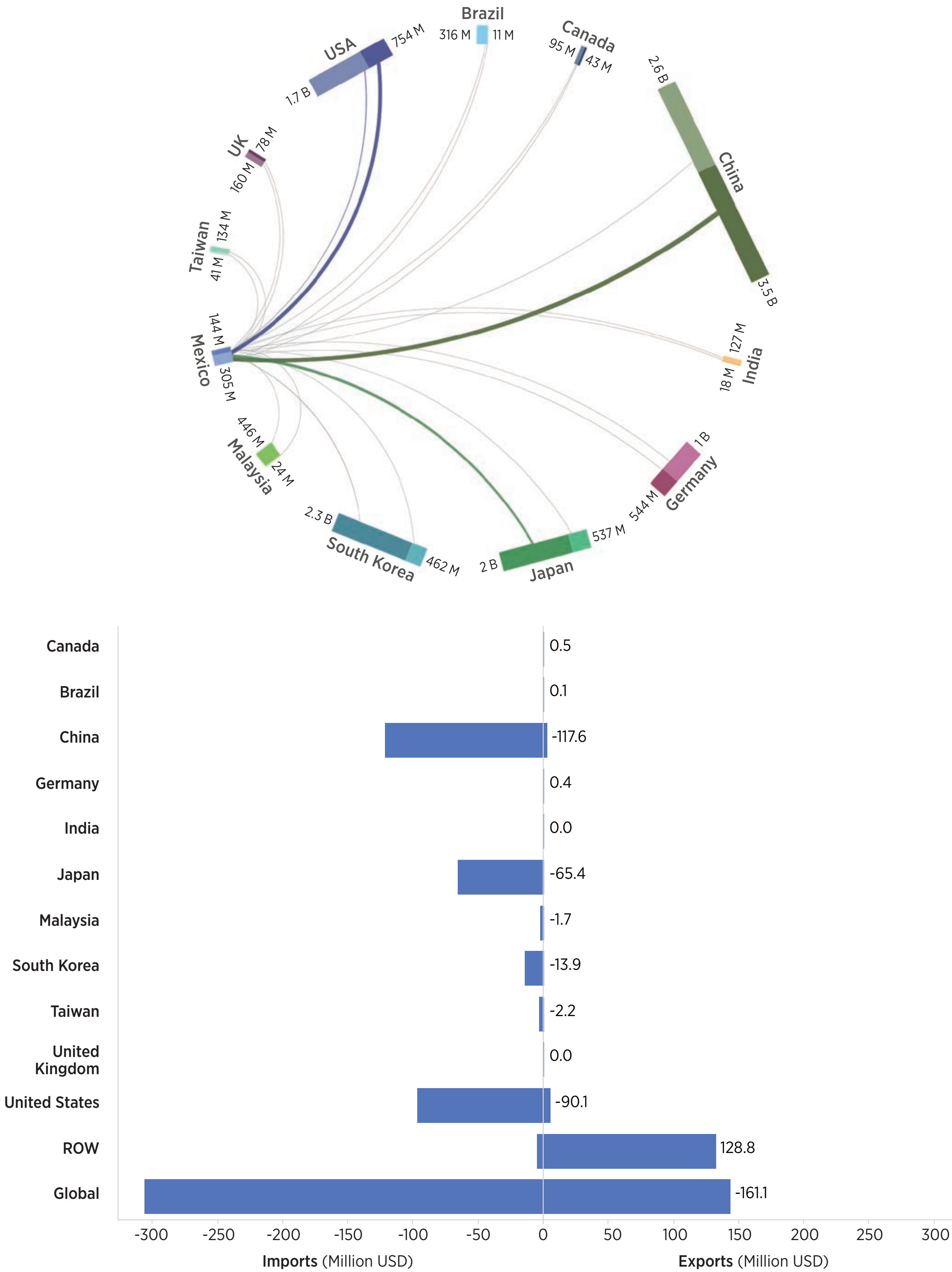


Figure 16-7. Mexico's 2014 Trade Flows and Balance of Trade for Li-ion Battery Cells. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

17 | South Korea: Clean Energy Manufacturing Profile

South Korea (Republic of Korea) has one of the world's largest economies, with a GDP of about 1.4 trillion USD in 2014. Approximately 93.2 GW of total electricity generation capacity power its economy, of which less than 5% comes from non-hydro renewables (EIA Beta 2015). Korea had a cumulative 2.24 GW of PV and 610 MW of wind generation installed in 2014 (IRENA 2015a), representing an estimated 10.7 billion USD of cumulative investment between 1999 and 2014.[51] South Korea leveraged its experience in manufacturing of heavy industrial machinery and electronics to emerge as a competitive force in clean energy manufacturing.

Key Findings

- In 2014, manufacturing of c-Si PV modules, wind turbine components, LED packages, and Li-ion battery cells for vehicles supported 3.7 billion USD in direct and indirect value added in South Korea. Of the four selected clean energy manufacturing technologies, LEDs supported the highest level of value added at 1.8 billion USD, followed by c-Si PV (1.3 billion USD), batteries (483 million USD), and wind ((160 million USD).
- South Korean manufacturing utilization rates are generally above global averages for each sector, excluding wind manufacturing.
- For the four technologies considered, in 2014, exports totaled 7.0 billion USD and imports totaled 3.8 billion USD, leaving South Korea with an overall positive balance of trade (3.2 billion USD).[52] The top trading partners with South Korea were Japan, China, and the United States. Among clean energy manufacturing products, South Korea exported the most rechargeable Li-ion batteries while importing the most LED packages.

Value Added: Clean Energy Manufacturing Impact on the Economy

In 2014, 8.5 billion in revenue from manufacturing of c-Si PV modules, wind turbine components, LED packages, and Li-ion battery cells for vehicles manufacturing supported 3.7 billion USD of value added (2.2 billion USD direct VA and 1.5 billion USD indirect VA) in South Korea (see Figure 17-1).[53]

Economy

- GDP (2014, nominal): 1,419 billion USD (World Bank 2016)
- Economy-wide value added contribution: 34% of all economic activity (gross output) in 2014
- Import contribution: 17% of gross output, 2014 (World Bank 2016)
- Five-year economic growth rate (2010–2014): 1.5% (World Bank 2016)
- Manufacturing, value added (% of GDP 2013): 31% (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 0.8

Trade

- Total imports (USD, 2014): 573 billion (WITS)
- Total exports (USD, 2014): 526 billion (WITS)
- Main trading partners (2015): China, United States, Hong Kong, Vietnam, Japan (exports)
- Main trading partners: China, Japan, United States, Germany, Saudi Arabia (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 93.2 GW (EIA Beta 2015a)
- Renewable share (excluding large hydro): 4.7% (EIA Beta 2015a; IRENA 2015a)
- Total investment in clean energy (USD, 2014): 99 billion (BNEF 2016)

RE and EE Targets

- Renewable portfolio standard for electricity suppliers: 2% in 2012, 10% by 2024
- Solar target: 1,500 MW by 2015

51. BNEF, 2016

52. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

53. Direct and indirect value added figures for each technology subcomponent do not sum to total value added figures for the technology as a whole. Technology subcomponents do not account for double counting whereas totals do.

Manufacturing of c-Si PV modules, and LED packages generated more direct than indirect value added across the supply chain. In contrast, Li-ion battery cell manufacturing and wind component manufacturing generated more indirect than direct value added.

Clean energy manufacturers in South Korea retain average levels of direct value added compared to other economies—26% for South Korea and 25% for the 12-economy average. Direct value added retained for South Korea's manufacturers was 23% for LED packages, 34% for c-Si PV modules, 23% for Li-ion battery cells, and 27% for wind turbine components.

Direct and indirect value added retained (Figure 17-1) is below average in South Korea, with clean energy manufacturers and their greater supply chains supporting 44% of total value added as a portion of clean energy manufacturing revenue, compared to the 12-economy average of 55%.

The economy-wide, direct, and indirect impacts of clean energy manufacturing are driven by characteristics of

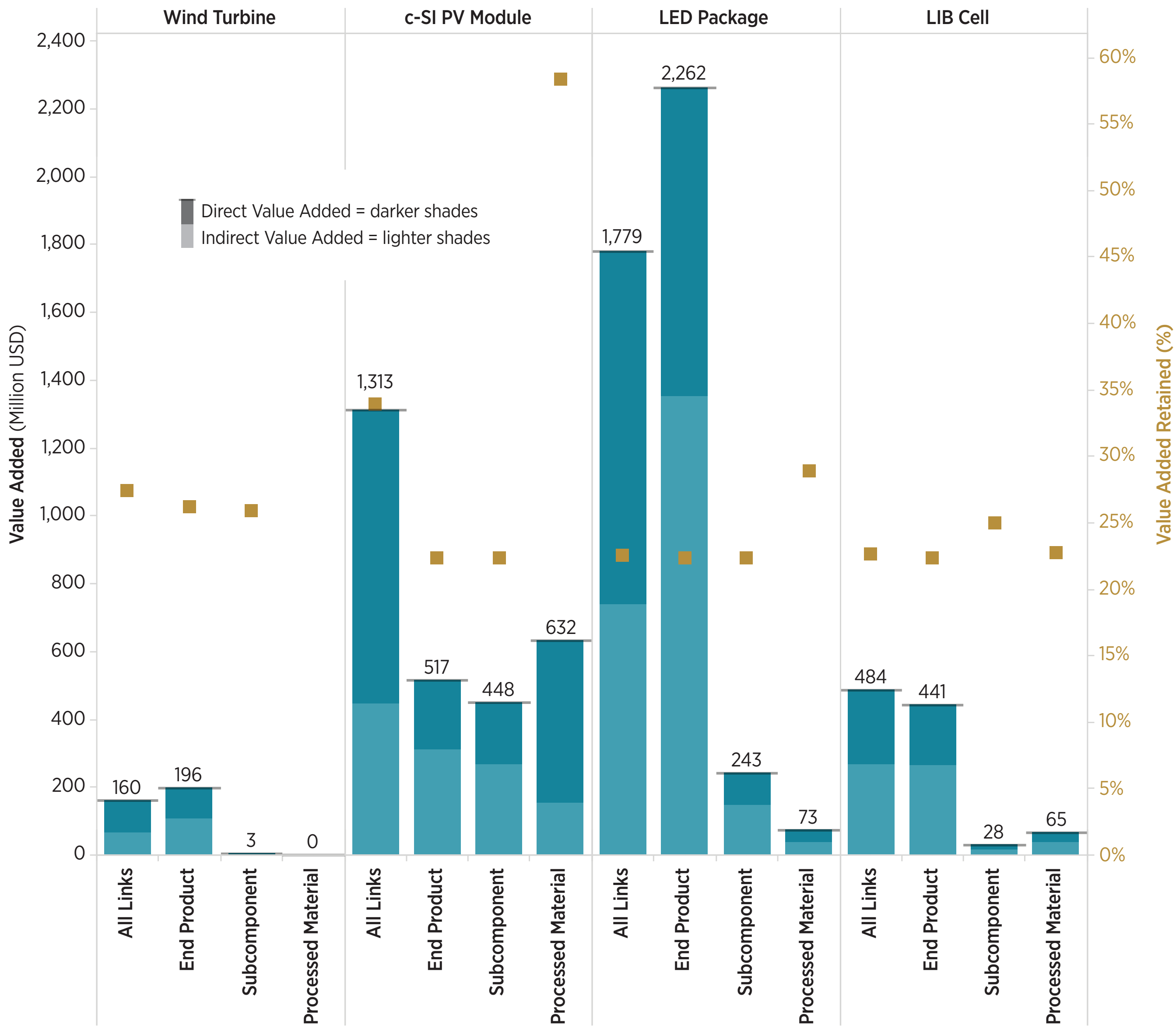


Figure 17-1. South Korea's value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

South Korea's economy: the second-highest level of imports of the 12 considered economies (indicative of less well-developed domestic supply chains) and low value added. Because South Korea's manufacturers rely more on imports, businesses that supply goods and services to manufacturers do not contribute as much to value added as they do in economies with more developed domestic supply chains. The portion of revenue that leaves the economy to pay for imported inputs is 17%; the 12-economy average is 11%. Value added across all industries as a portion of economy-wide revenue is 34%, less than the 46% average.[54]

Manufacturing Landscape: Demand, Manufacturing Capacity and Production

South Korea's manufacturing sector is a significant contributor to the economy, accounting for 31% of national GDP in 2014, the highest percentage of any economy in this report and equivalent to 440 billion USD. The economy's main industries include steel, automobile, and electronics manufacturing. South Korea is the second largest producer of semiconductors in the world, behind the United States (ITA 2016c).

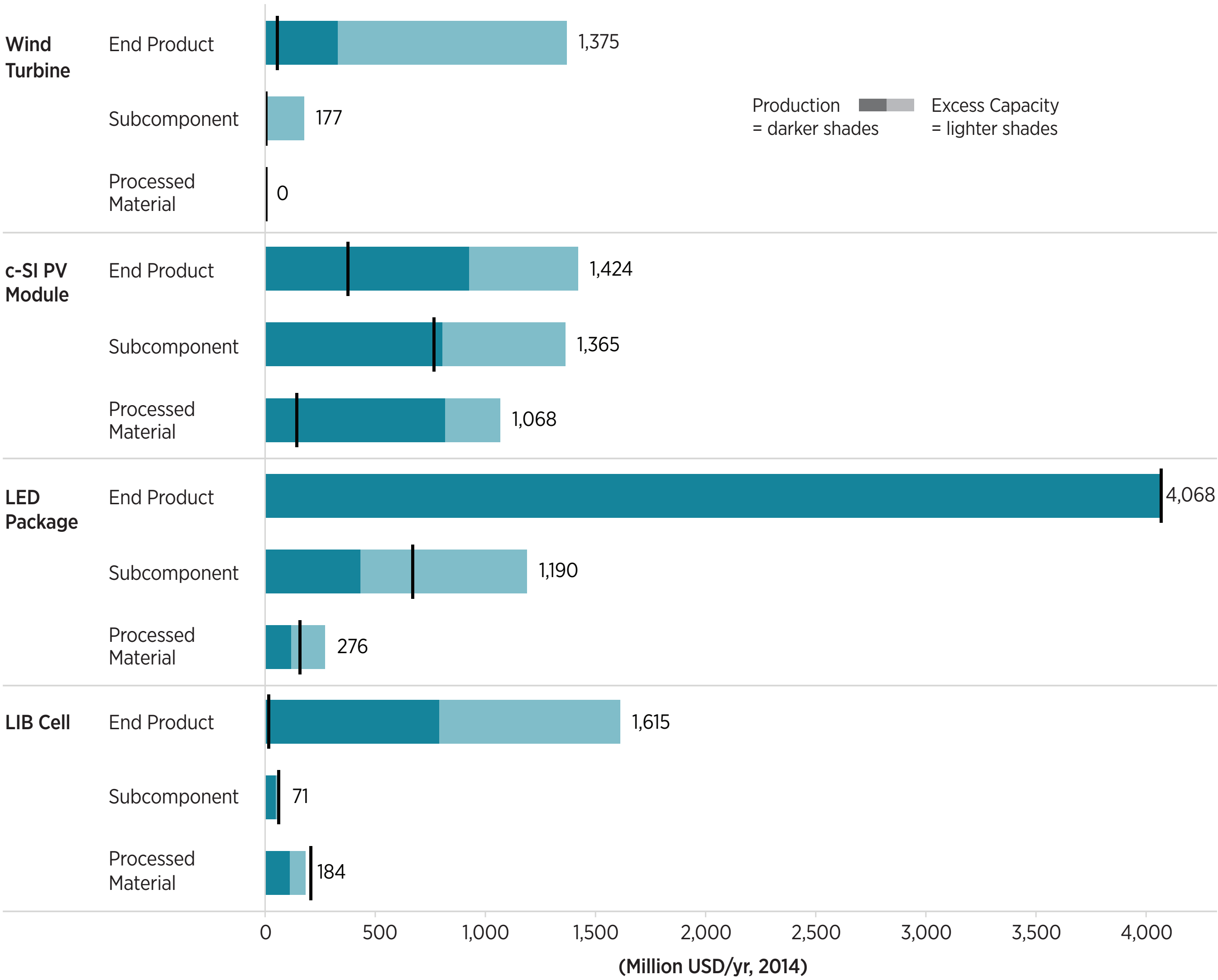


Figure 17-2. South Korea's demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies (for LED packages, assumed production equal to demand due to lack of demand data), 2014. See methodology report for data quality discussion.

54. OECD STAN database (2015)

In 2014, South Korea was a leader in LED package and Li-ion battery cell manufacturing across the supply chain; and maintained a solid manufacturing base for c-Si PV modules and related materials and components. South Korea hosted a minor amount of wind turbine component manufacturing. Figure 17-2 shows South Korea's 2014 manufacturing capacity, production, and demand for the four technologies included in this analysis.

In 2014, South Korea hosted a minor amount of land-based wind nacelle, tower, and generator manufacturing capacity, totaling 1,800 MW (2% share of the global total), 1,700 MW (3% share), and 3,300 MW (7% share), respectively. C-Si PV module, cell, wafer, and polysilicon annual manufacturing capacity stood at 2,000 MW (2% share), 2,200 MW (3% share), 2,400 MW (4% share), and 11,600 MW (16% share), respectively. In 2014, annual manufacturing capacity for LED packages, chips, and substrates was 43.7 billion packages (27% of the global total), 26.8 billion packages (17% of global), and 68.4 billion packages (20% of global), respectively. South Korea was home to the fourth-highest share of manufacturing capacity for LDV Li-ion cells and separators, and ranked third in cathode, anode, and electrolyte capacity in 2014. Annual cell, cathode, anode, separator, and electrolyte manufacturing capacity totaled 4,400 MWh (19% share), 1,500 MWh (9% share), 900 MWh (5% share), 2,700 MWh (7% share), and 3,800 MWh (19% share), respectively, in 2014.

South Korean manufacturing utilization rates are generally above global averages in each technology sector. South Korea's PV module manufacturers achieved an average utilization rate of 65%, while their Li-ion cell manufacturers averaged 49%. These rates are well above global averages of 55% and 41% for PV modules and Li-ion cells, respectively.

On the demand side:

- Demand for wind turbines in South Korea was just 50 MW in 2014, much less than 1% of total global demand that year.
- South Korean demand for PV modules was relatively small in 2014, totaling 530 MW or 1% of the global total.
- South Korea is a leading demand market for lighting LED packages, with a demand of 43.7 billion packages in 2014. This constituted 27% of global demand in the same year, and was the second largest single economy market in the world behind Japan.
- South Korea was a relatively small demand market for Li-ion cells in 2014, with only 30 MWh of demand, less than 1% of the global total.

Trade Landscape: Balance of Trade and Trade Flows

Korea has comprehensive free-trade agreements with several economies and regional groups (i.e. Association of Southeast Asian Nations (ASEAN), India, the EU, Peru, and the United States). These agreements cover goods, services, and investment, and are seen by proponents of free trade as a catalyst for reforming the economy and raising competitiveness through further liberalization and deregulation in certain sectors. The customs tariff is one of Korea's main trade policy instruments as well as a major and increasing source of tax revenue (6% of total tax revenue in 2010) (WTO 2012). In 2008, South Korea introduced a 19% surcharge on foreign PV goods. However, it was removed in 2009. In 2004, South Korea also halved import duties for components and equipment used in renewable energy power plants that cannot be manufactured domestically; the premium was abrogated starting in 2016 (Boekhoudt 2014).). Figures 17-3 through 17-7 show South Korea's balance of trade in the select clean energy technologies both collectively and individually.

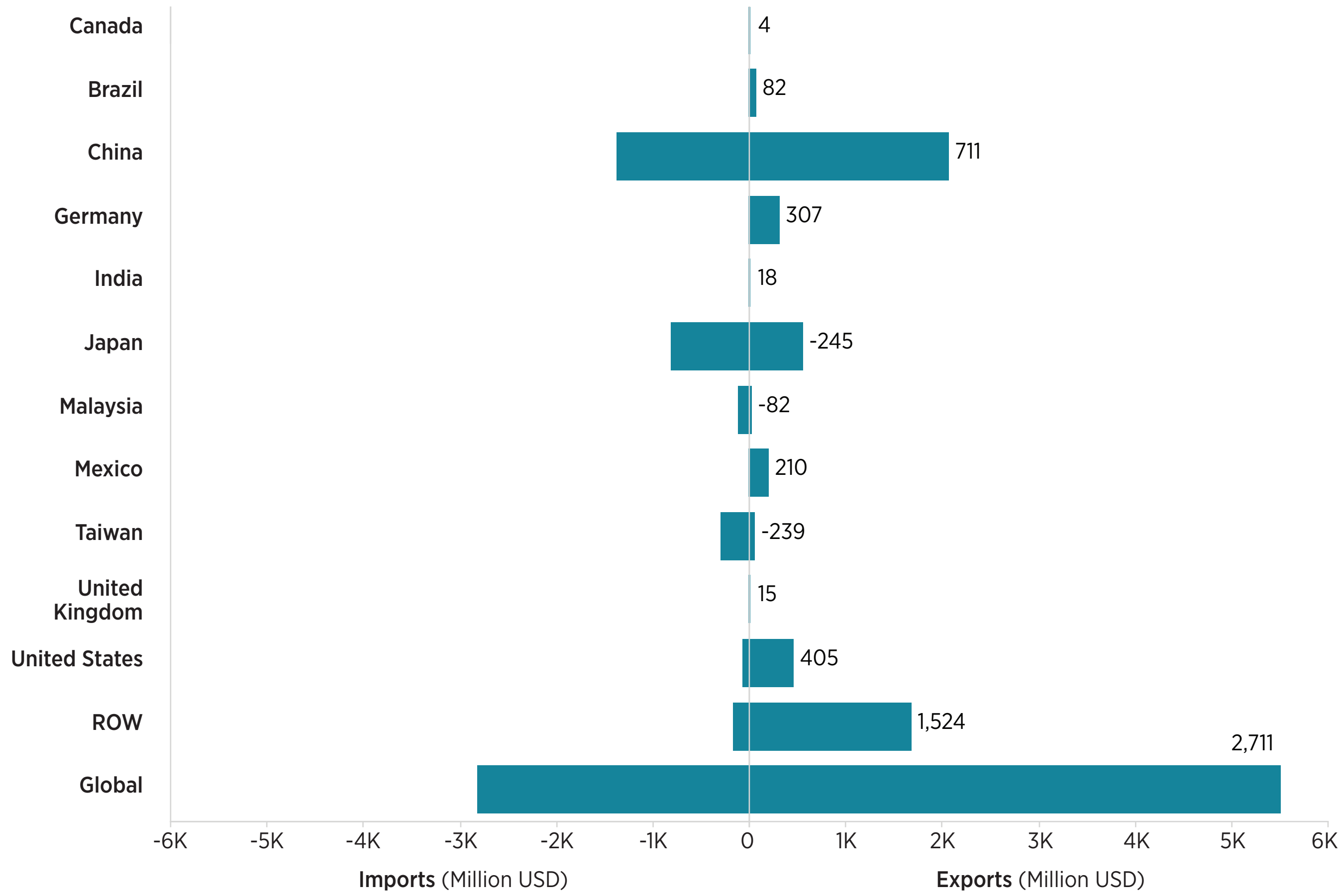


Figure 17-3. South Korea's balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

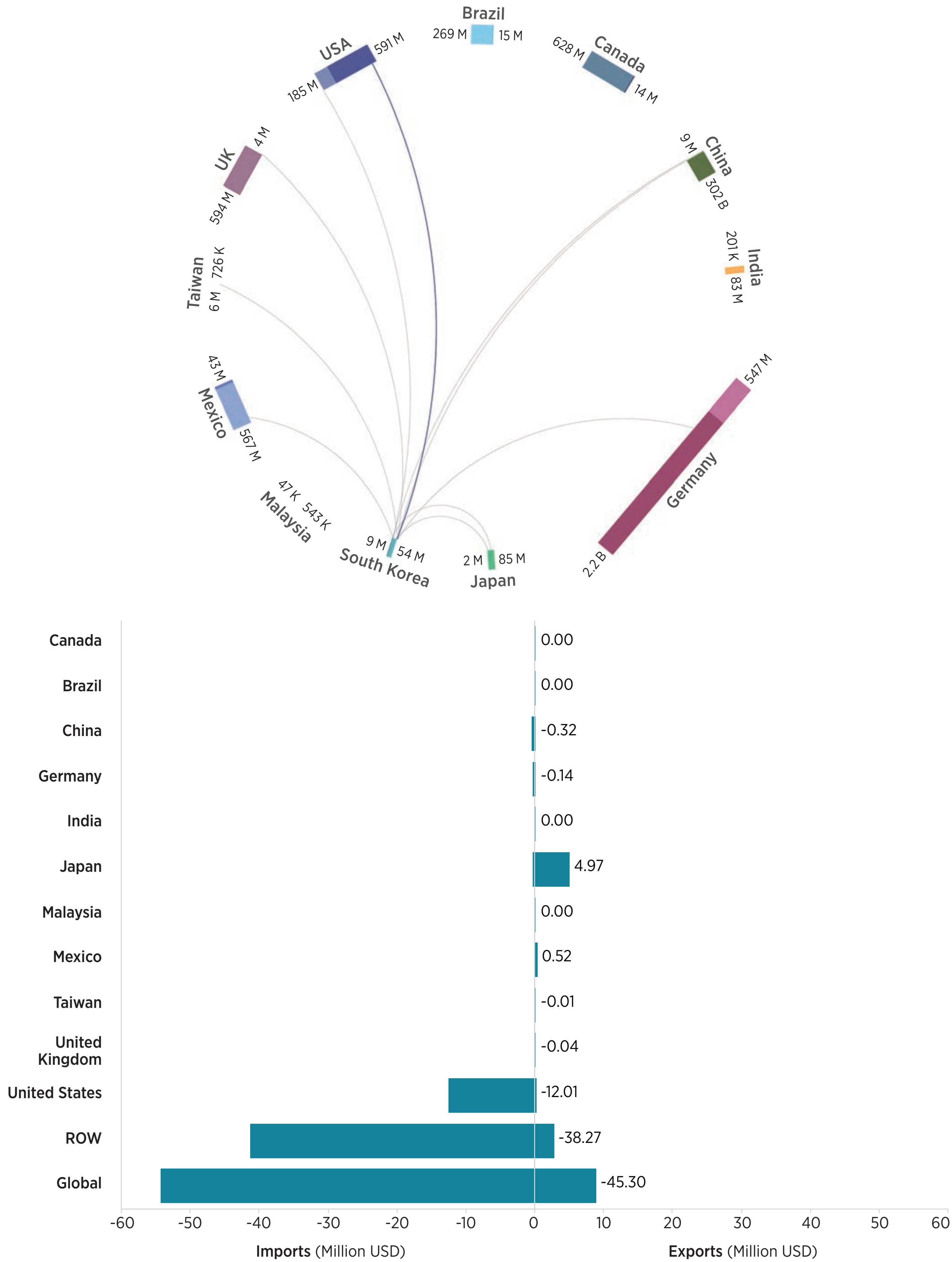


Figure 17-4. Trade between South Korea and key partners in wind turbine generator sets, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

Figure 17-5. Trade between South Korea and key partners in c-SI PV modules, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

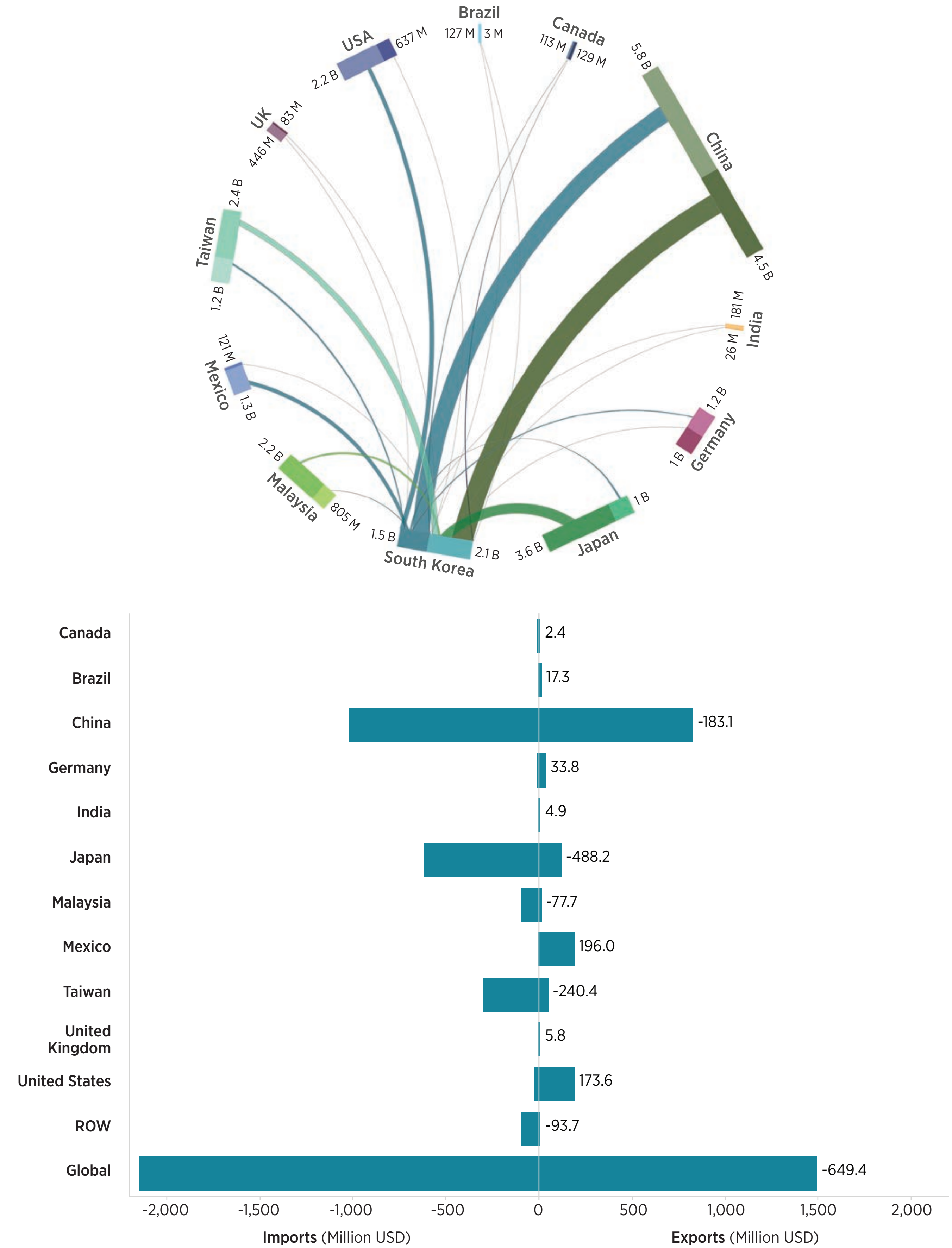


Figure 17-6. Trade between South Korea and key partners in LED packages, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

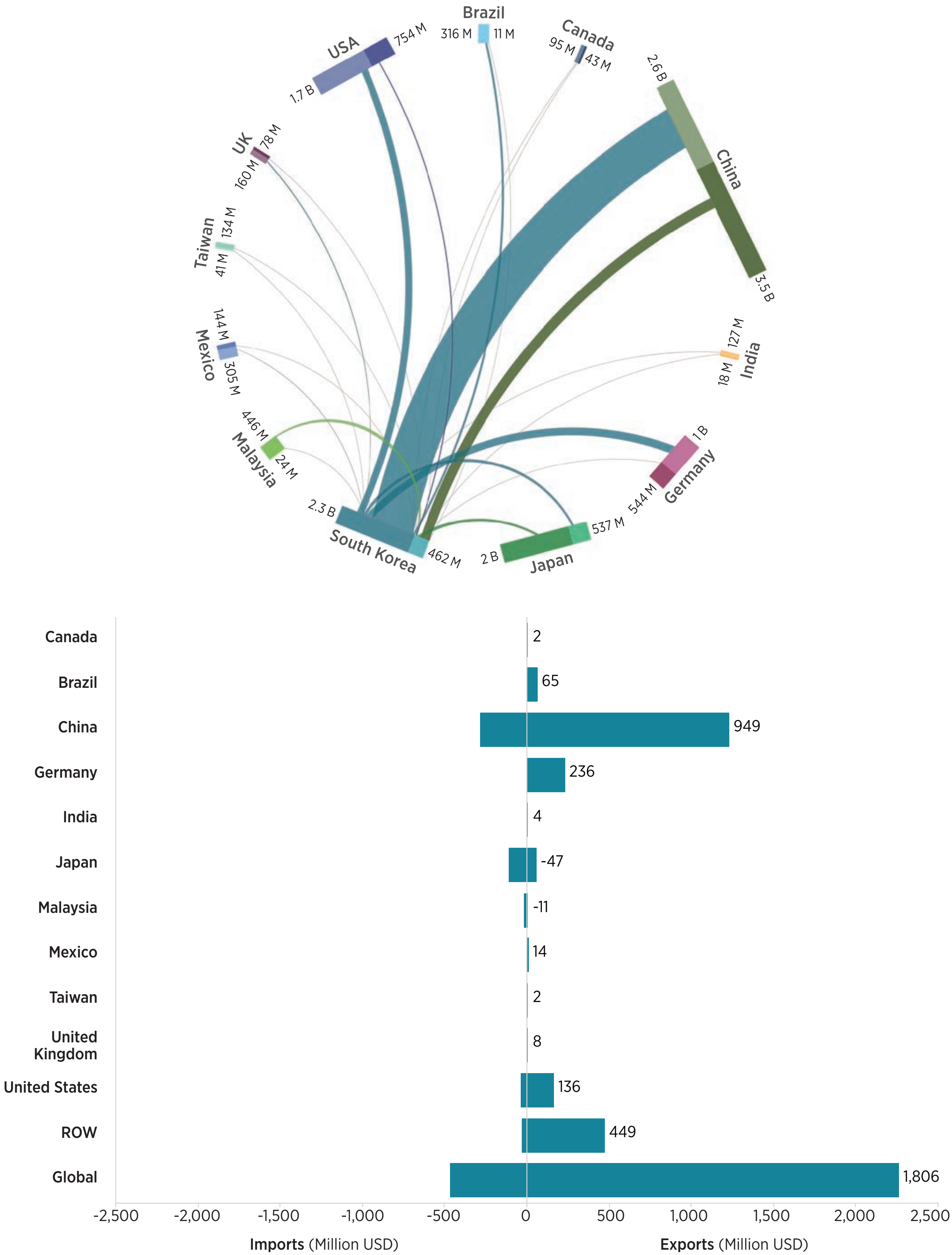


Figure 17-7. Trade between South Korea and key partners in Li-ion cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

18 | United Kingdom: Clean Energy Manufacturing Profile

The United Kingdom (UK) is the fifth-largest economy in the world, and has made commitments to low carbon growth and a climate resilient future. As many of the UK's commitments have been made in partnership with the EU, the recent referendum decision for the UK to exit the EU leaves much to be determined about the future of the UK's clean energy transition. In addition, the UK has made a handful of recent policy adjustments, which reduce or remove support for clean energy projects (Warren 2015). As of 2014, the UK had a cumulative 5.2 GW of solar and 12.8 GW of wind generation installed (IRENA 2015a).

Key Findings

- In 2014, manufacturing of wind turbine towers (for land-based turbines) and Li-ion vehicle battery cells and electrolytes produced approximately 190 million USD of value added to UK's GDP. The UK only produced LDV Li-ion batteries and wind components, which supported 73 million USD and 117 million USD in value added, respectively.
- In 2014, the UK supported a small amount of wind-related and LDV Li-ion battery manufacturing and no significant PV or LED manufacturing across the supply chain. Relative to other producer nations within each technology sector, UK has rates of manufacturing utilization below global averages.
- For the four technologies considered, in 2014, exports totaled 362 million USD and imports totaled 3.4 billion USD, leaving UK with an overall negative balance of trade (-3.0 billion USD) in clean energy manufacturing products.[55] The top trading partners with the UK were China, Japan, and Germany.

Value Added: Clean Energy Manufacturing Impact on the Economy

As illustrated in Figure 18-1, in 2014, manufacturing of wind components produced 117 million USD in value added. LDV Li-ion battery production supported value added of 73 million USD, for a total of 190 million USD. The only component of Li-ion batteries produced in the UK was cells, and the only component of wind produced was towers.

Direct value added was greater than indirect for both technologies: 50 million USD for batteries and 79 million USD for wind. Indirect impacts were 24 million USD and 38 million USD, respectively.

Economy

- GDP (nominal USD, 2014): 2,990 billion (World Bank 2016)
- Direct value added contribution: 49% of gross output
- Import contribution: 10% of gross output
- GDP growth rate (five year average 2010–2014): 1.96% (World Bank 2016)
- Manufacturing, value added (% of GDP 2013): 10.8 (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 1.2

Trade

- Total imports (USD, 2014): 511 billion (WITS)
- Total exports (USD, 2014): 694 billion (WITS)
- Main trading partners: United States, Germany, Switzerland, China (exports)
- Main trading partners: Germany, China, United States, Netherlands (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 83.543 GW (BNEF 2016)
- Renewable share: 32.2% (BNEF 2016; IRENA 2015)
- Total investment in clean energy (USD, 2014): 17.6 billion

RE and EE Targets

(DECC 2011, European Commission 2016a)

- 15% renewable energy in final energy consumption by 2020
- 18% reduction in final energy consumption by 2020 relative to 2007 business-as-usual projection

55. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

The average direct value added retained across technologies was greater than the average across all economies in this report: 46% compared to the 12-economy average of 25%. This is true for each technology produced in the UK as well. The UK retained 45% of direct value added from battery production compared to a 33% average across economies and 46% for wind component production compared to 30% across economies. Both numbers are slightly lower than value added divided by all economic activity (gross output) across all industries in the UK. While clean energy manufacturers in the UK retain more value added than similar producers in other economies, they do not produce more value added than the UK average.

Total value added (direct and indirect) retained (Figure 18-1) was slightly lower than averages across all economies in this report. The percentage for batteries was 67% in the UK compared to 68% across all economies and 68% for wind compared to 72% across all economies in this report. Batteries and wind, however, tend to support higher percentages of value added than LEDs and PV, so the 67% UK average across the technologies that it produces was greater than the 55% average across all technologies and economies in this report.

- The relatively greater direct than indirect impacts in the UK are driven by characteristics of the affected industries rather than the economy as a whole. Value added as a percentage of all economic activity in the UK

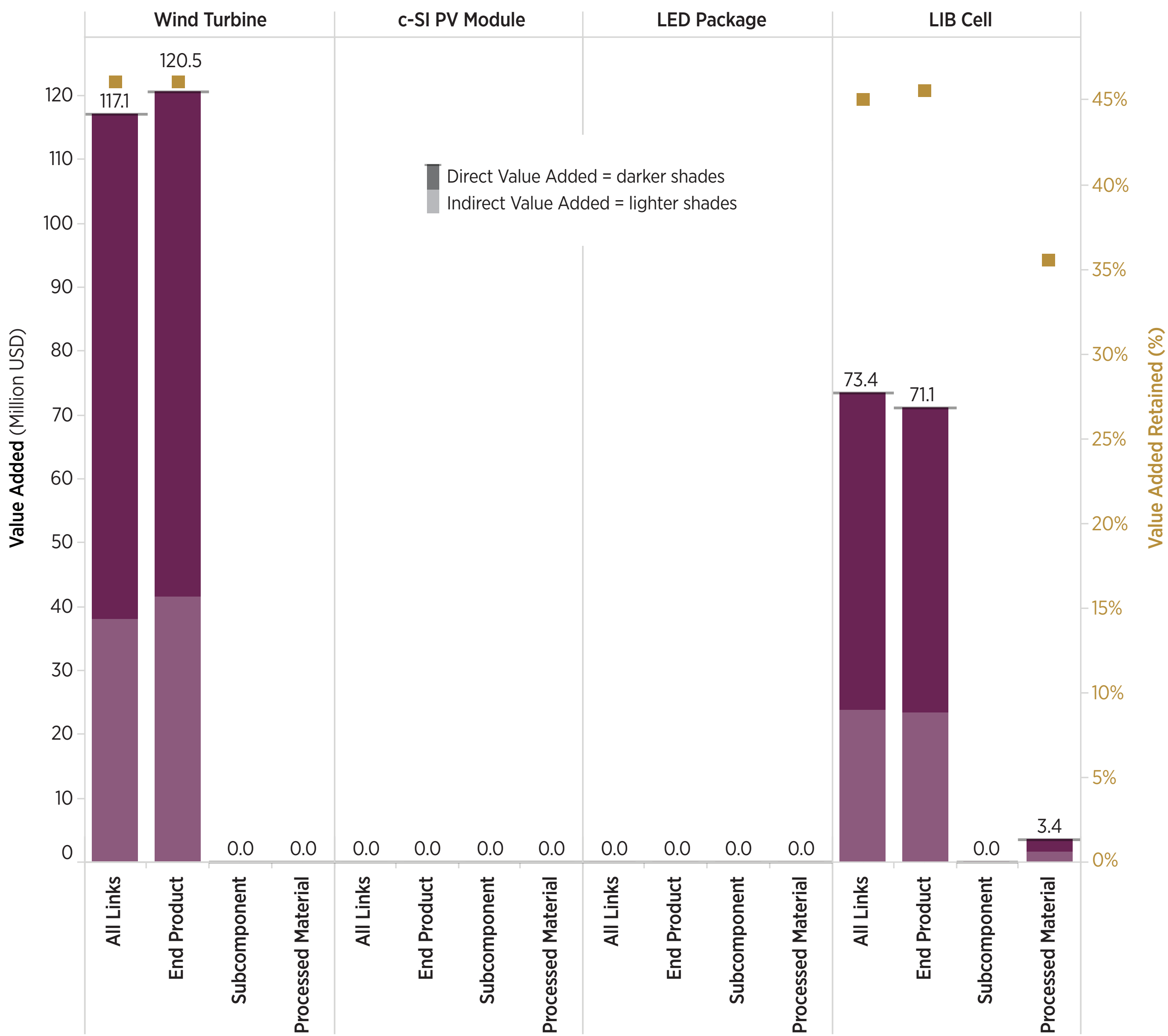


Figure 18-1. United Kingdom value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

(gross output) is about 49% across all industries, placing the UK in the middle of the 12 economies. Similarly, the percentage of inputs used by businesses in production is 10%, just below the 11% average.

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

In 2014, the manufacturing sector contributed 10.8% to the UK GDP, equivalent to 321 billion USD (World Bank 2016). To help strengthen its manufacturing sector, the UK has implemented a number of policies in the last five years. For example, the Advanced Manufacturing Supply Chain Initiative provides funding to encourage the "co-location" of supply chains and prime producers by helping to expand already operating suppliers and to encourage the development new suppliers. High Value Manufacturing Catapult Centers have been established across the economy to enable companies to access equipment, expertise, and information needed to develop and commercialize ideas and innovations in areas such as composites, advanced manufacturing, and forming processes (House of Commons Library 2015).

In 2014, the UK supported a relatively small amount of wind-related and LDV Li-ion battery manufacturing across the supply chain compared with the other economies in this report; no significant PV or LED manufacturing was located in the UK. Figure 18-2 shows the UK's 2014 demand, manufacturing capacity, and production for the four technologies included in this analysis.

In 2014, the UK was home to 1,000 MW of land-based wind tower (2% share of the global total) annual manufacturing capacity, and tower production totaled 890 MW. The UK was home to a material amount LDV Li-ion cell and

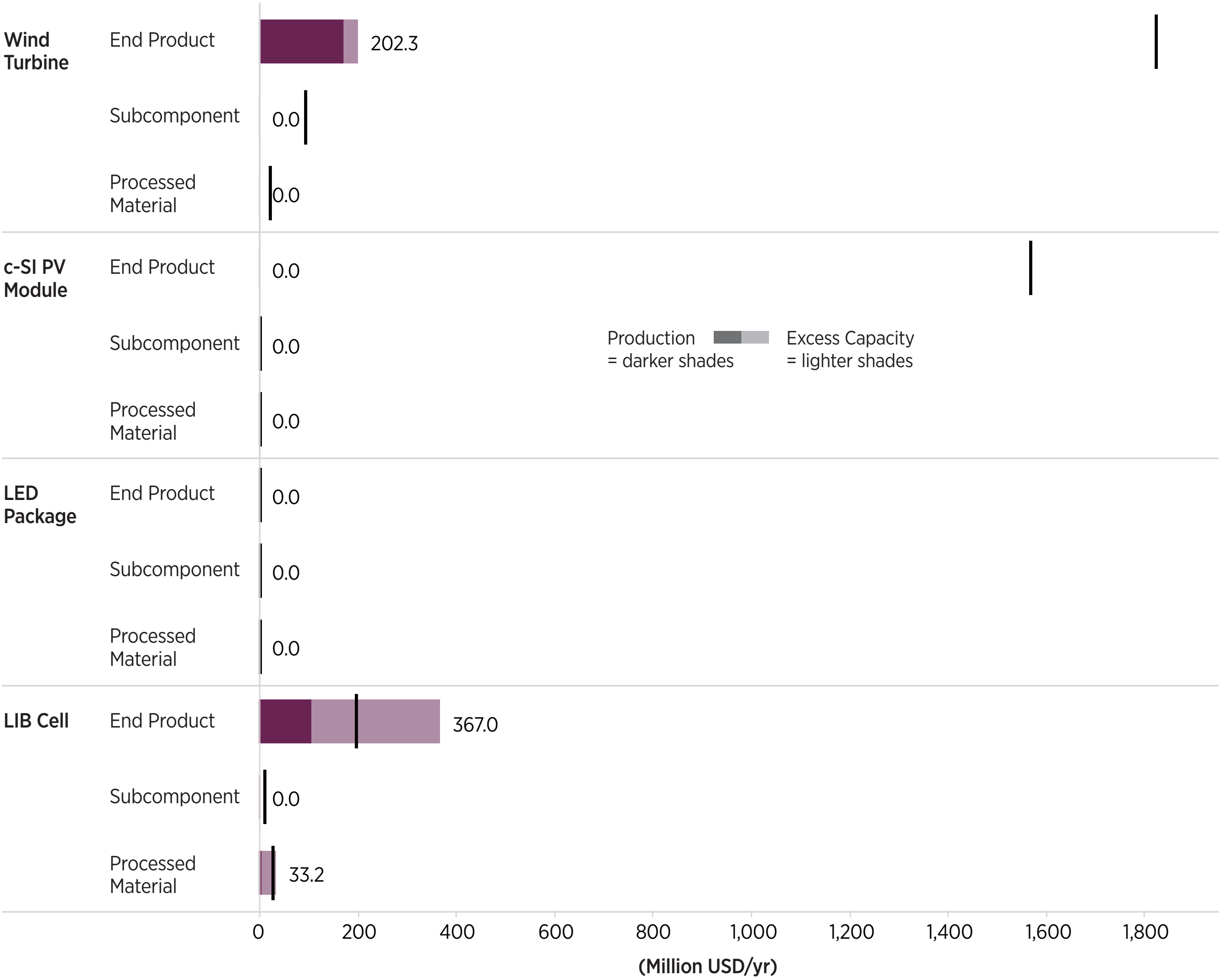


Figure 18-2. United Kingdom demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies, 2014. See methodology report for data quality discussion.

electrolyte manufacturing capacity in 2014, totaling 1,000 MWh (4% share of the global total) and 1,500 MWh (7% share), respectively, of annual capacity. Production in 2014 totaled 290 MWh of Li-ion cells and 230 MWh of electrolytes in 2014.

Relative to other economies within each technology sector, UK manufacturing utilization rates are lower than global averages. The UK's Li-ion cell manufacturers averaged 29%, below the global average of 41%.

On the demand side:

- Domestic demand for wind turbines was 1,700 MW in 2014, or 3% of total global demand. This made the UK the seventh-largest demand market in the world.
- Domestic demand for PV modules totaled 2,200 MW in 2014, or 6% of total global demand. This made the UK the fourth-largest demand market globally in that year. Demand is expected to grow steadily through 2020, making the UK the fifth-largest market in terms of cumulative demand between 2015 and 2020 (NREL estimates using data from BNEF 2015, James 2015, Labastida and Gauntlett 2015).
- The UK also had a domestic LDV Li-ion cell demand of 530 MWh in 2014 (5% share of total global demand), making it the fifth-largest demand market in the world.

Trade Landscape: Balance of Trade and Trade Flows

The United Kingdom maintains an open and transparent trade system aligned with the European Union's common policies and laws regarding trade. With respect to clean energy manufacturing, the EU has established import duties on PV products to counteract alleged Chinese subsidies and price-cutting. Specifically, the EU has established import duties on Chinese solar Chinese PV products (European Commission 2015). Subsequently China placed duties on polysilicon from EU economies beginning in 2014. (ICTSD 2014)

Balance of trade and trade flows for the supply chain links for which trade data are available are presented in Figures 18-3 through 18-7. In 2014, the UK was a net importer, maintaining a -2.2 billion USD balance of trade for all commodities included in this analysis.

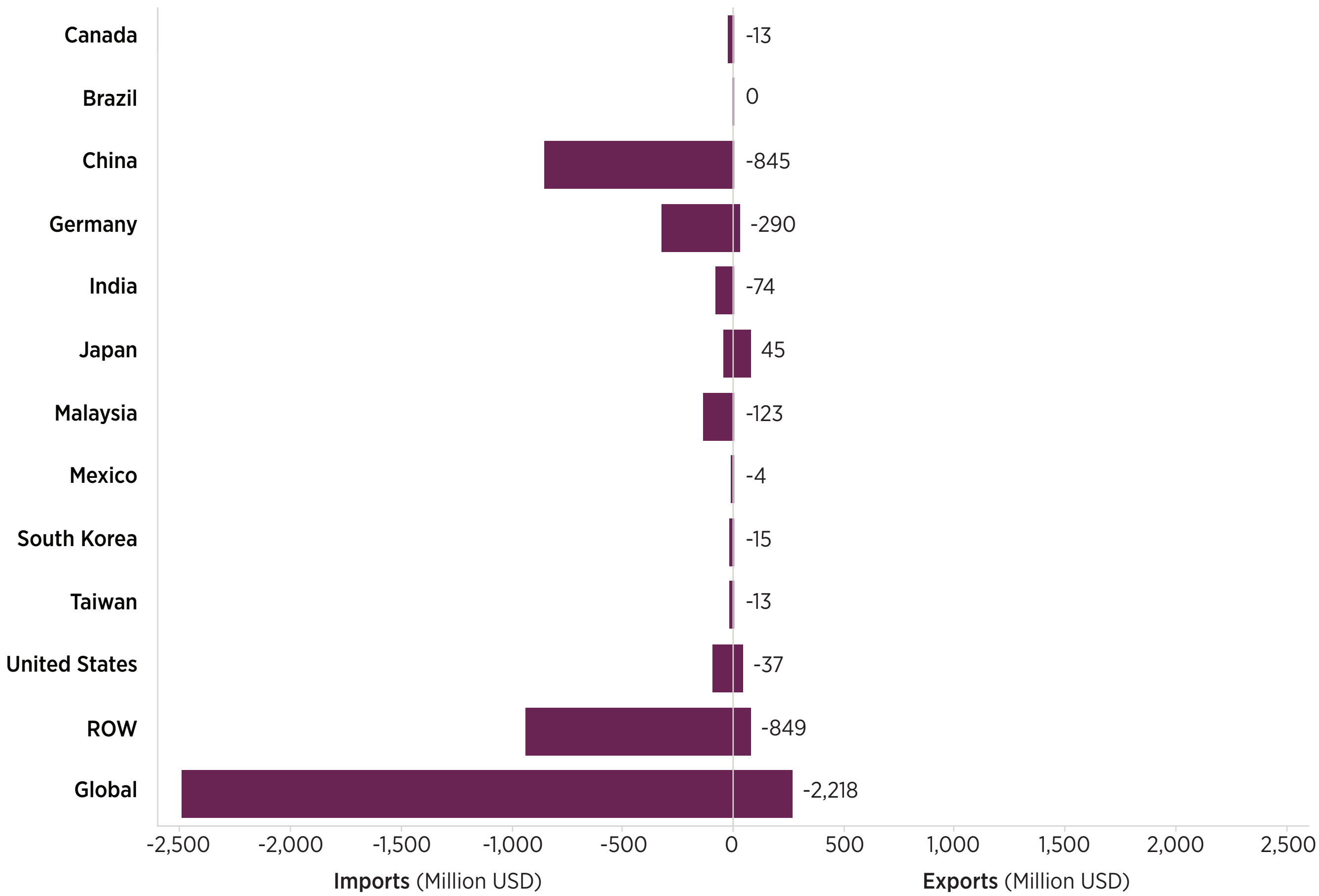


Figure 18-3. United Kingdom balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

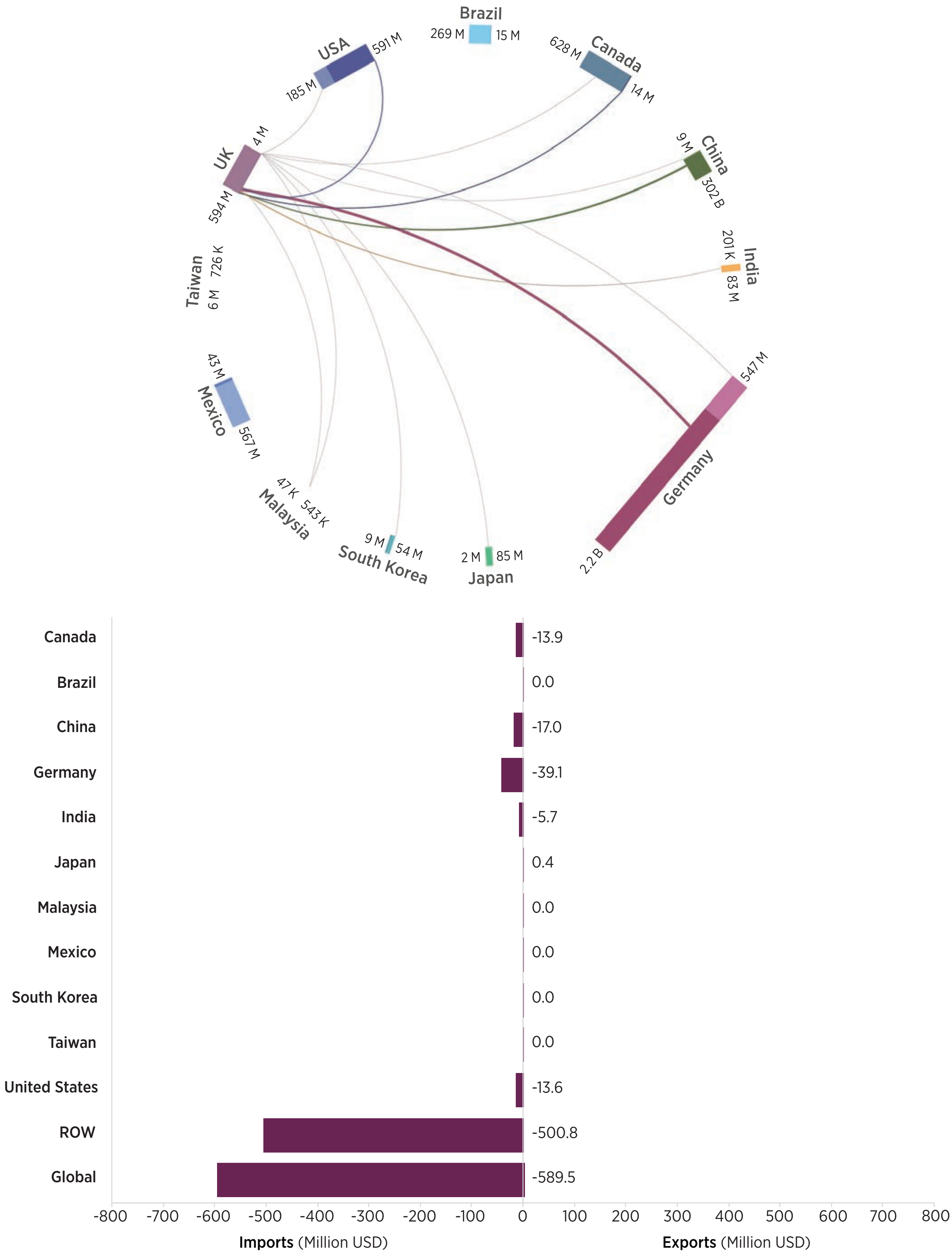


Figure 18-4. United Kingdom 2014 trade flows and balance of trade for wind turbine generator sets. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

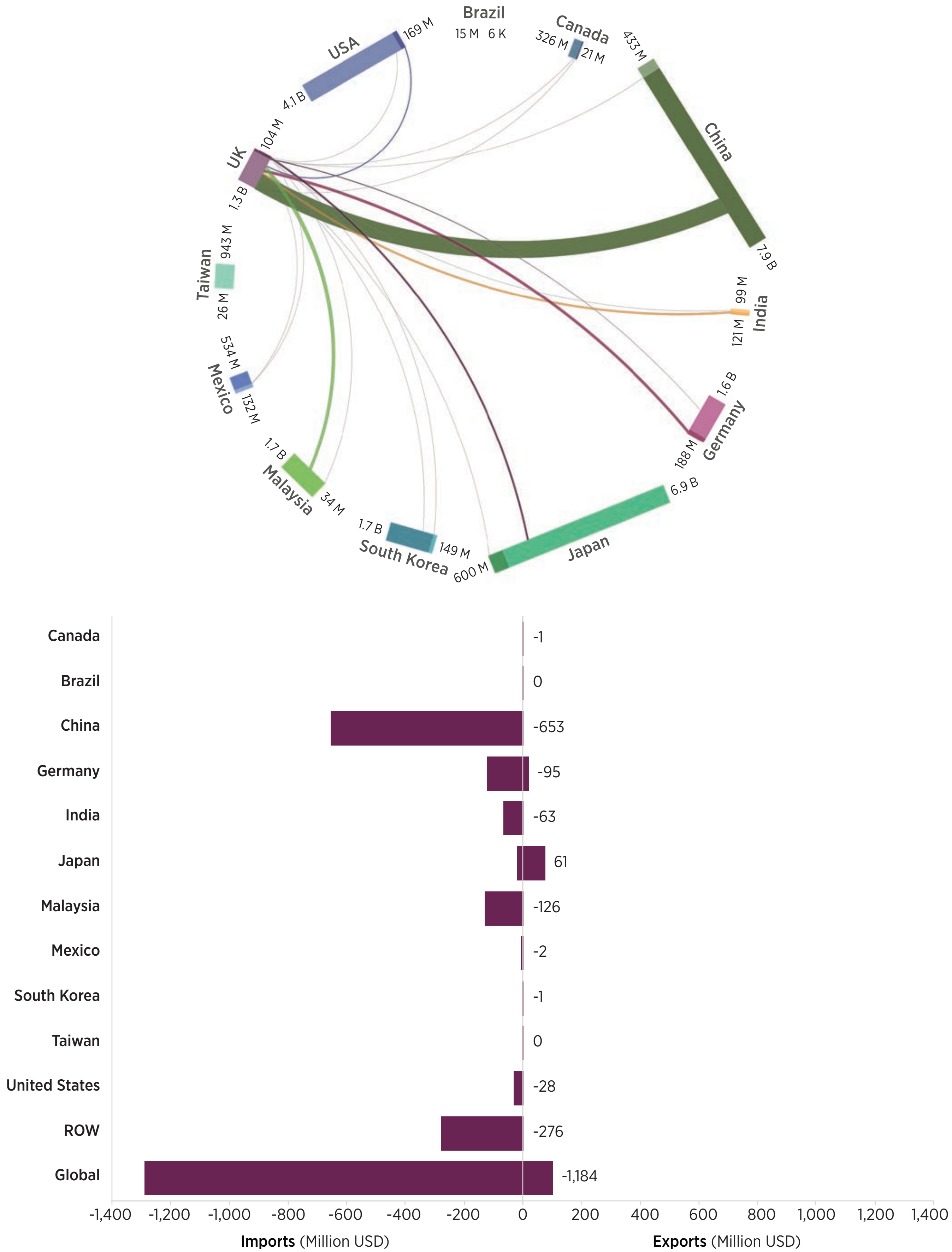
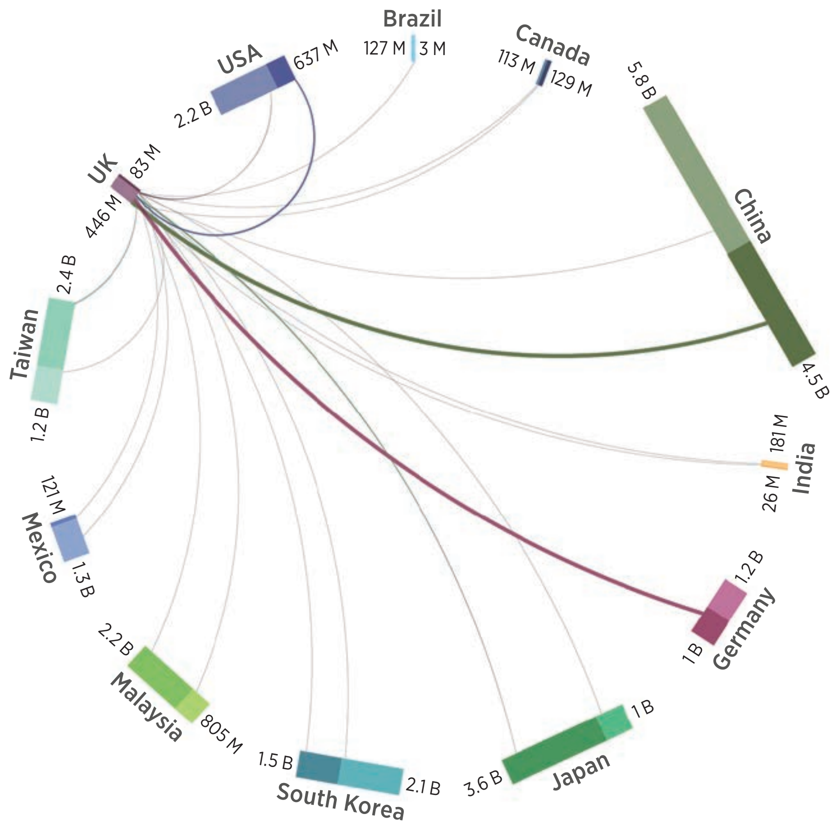


Figure 18-5. United Kingdom 2014 trade flows and balance of trade for PV modules. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.



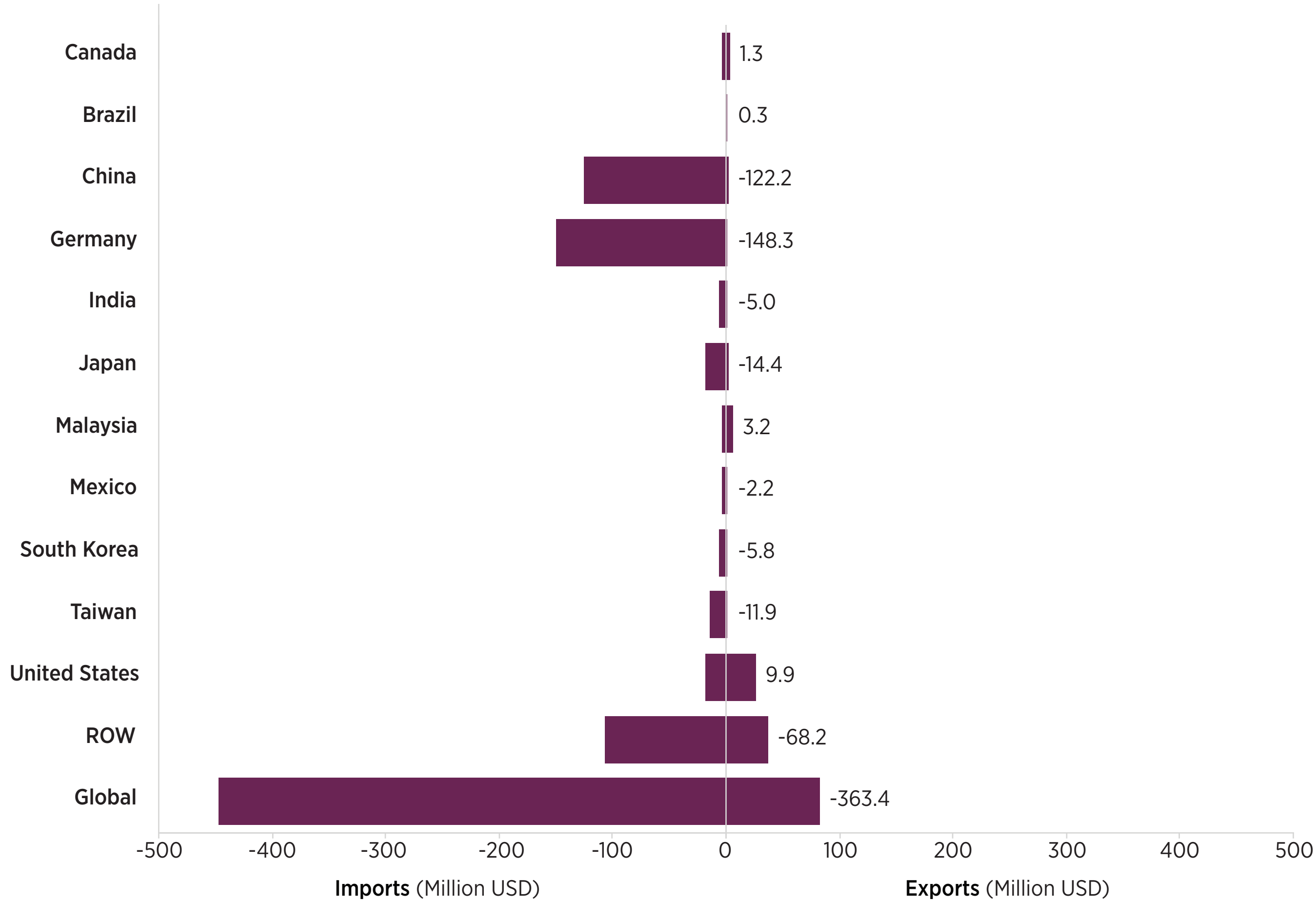


Figure 18-6. United Kingdom 2014 trade flows and balance of trade for LED Packages. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

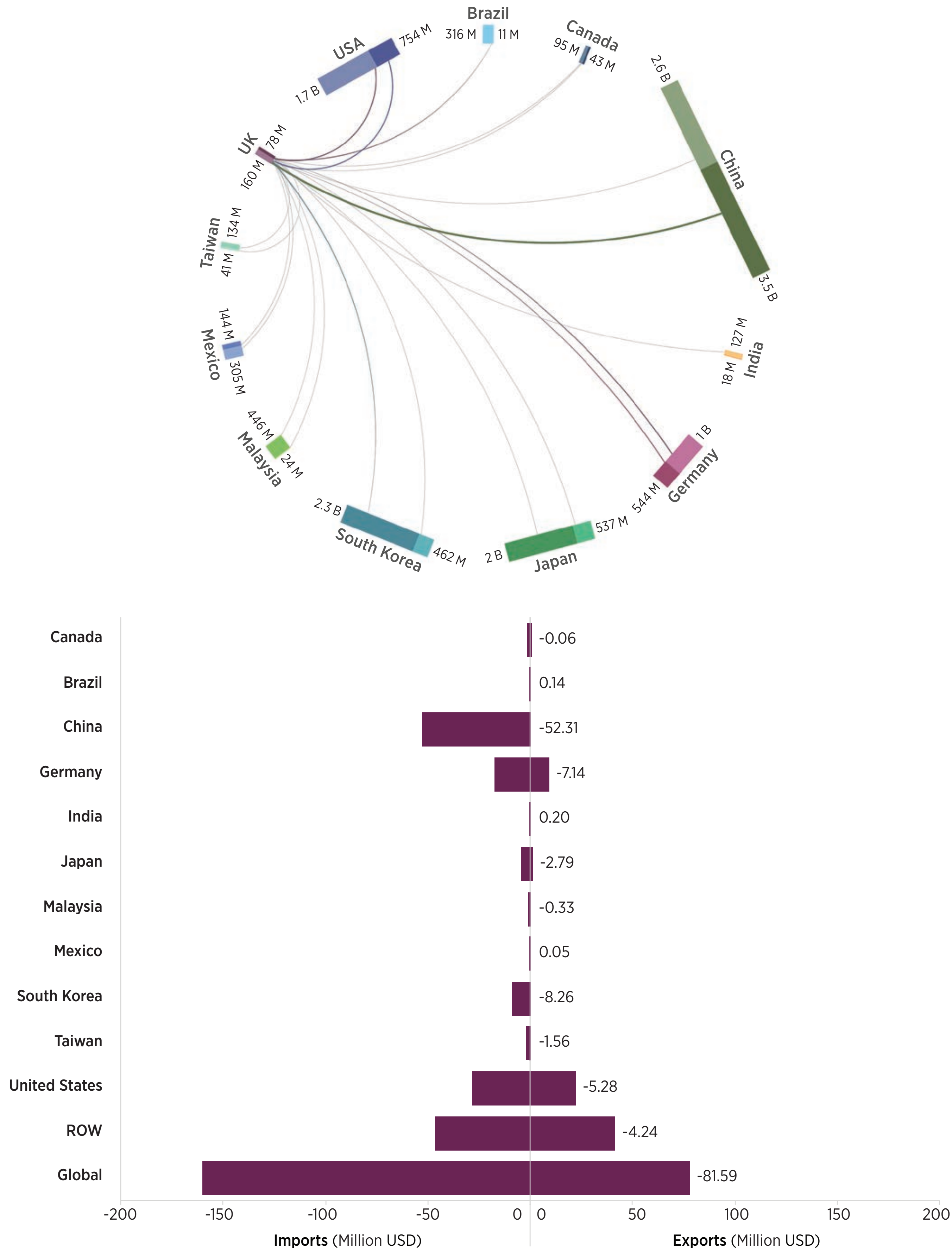


Figure 18-7. United Kingdom 2014 trade flows and balance of trade for Li-ion battery cells. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

19 | United States: Clean Energy Manufacturing Profile

The United States has the world's largest economy, with a GDP of more than 17 trillion USD. Approximately 1,173 GW of total electricity generation capacity powers the U.S. economy, of which 8% comes from non-hydro renewables. Annual U.S. wind and solar generation installation totaled 11.5 GW in 2014 (IRENA 2015a), with an estimated 51 billion USD of investment.[56] Cumulative installations were 18.3 GW of solar and 64.8 GW of wind in the same year (IRENA 2015a). Deployment of innovative technologies and policies that support clean energy manufacturing and demand at home and abroad have fostered mature manufacturing supply chains in the four technologies covered in this analysis. In addition, that demand drives dynamic trade activities along the supply chain.

Key Findings

- In 2014, manufacturing of nacelles, blades, wind towers, polysilicon, and Li-ion battery cells contributed 6.2 billion USD in value added to the United States economy. This was 3.8 billion USD from wind, 1.4 billion USD from c-Si PV, 611 million USD from LDV Li-ion batteries, and 479 million USD from LEDs.
- In 2014, the United States was a global leader in manufacturing nacelles, blades, towers, and generators for wind turbines. The United States is also home to a strong manufacturing base for polysilicon for c-Si PV modules, and LDV Li-ion battery cells and electrolytes. United States manufacturing utilization rates are generally below global averages for each technology sector.
- For the four technologies considered, in 2014, exports totaled 4.1 billion USD and imports totaled 8.3 billion USD, leaving the United States with an overall negative balance of trade (-4.2 billion USD).[57] Of economies and technologies included in this report, the top trading partners with the United States were China, Japan, and Canada. Among clean energy manufacturing products, the United States exported the most polysilicon while importing the most PV cells and modules.

Economy

- GDP (nominal USD, 2014): 17,419 billion (World Bank 2016)
- Direct value added contribution: 55% of gross output
- Import contribution: 5% of gross output
- Five-year economic growth rate (2010–2014): 2.2% (World Bank 2016)
- Manufacturing, value added (% of GDP 2013): 12.4 (World Bank 2016)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate: 1.0

Trade

- Total imports (USD, 2014): 1,620 billion (WITS)
- Total exports (USD, 2014): 2,411 billion (WITS)
- Main trading partners: Canada, Mexico (exports)
- Main trading partners: China, Canada, Mexico (imports) (CIA 2016)

Energy Sector

- Total installed generation capacity: 1173 GW (EIA 2016)
- Renewable share (excluding large hydro): 9% (EIA 2016; IRENA 2015)
- Total investment in clean energy (2014): 51 billion USD

RE and EE Targets

- No national RE target. Most states have their own renewable portfolio standard or goal
- U.S. lighting efficiency standards

56. BNEF, 2016

57. Figures are only exports and imports covered by the ITC. For wind these only include generator sets and battery trade is Li-ion batteries for all applications.

Value Added: Clean Energy Manufacturing Impact on the Economy

As illustrated in Figure 19-1, the United States produced components for all four selected technologies, supporting a combined 6.2 billion USD in value added. Most of this—about 60%—came from wind, which supported 3.8 billion USD. C-Si PV supported an additional 1.4 billion USD, followed by LDV Li-ion batteries (611 million USD) and LEDs (479 million USD).

Across the supply chain of all four clean energy technologies, clean energy manufacturing generated more direct than indirect value added across the supply chain. Wind supported 2.0 billion USD direct and 1.8 billion USD indirect value added. Solar PV supported 904 million USD direct and 449 million USD indirect. Batteries supported 444 million USD direct and 166 million USD indirect, and LEDs supported 377 million USD direct and 102 million USD indirect.

Combined, for the four clean energy technologies included in the benchmark report, the direct value added retained was 48%, the highest of the 12 economies included in the report and nearly twice the 25% average across all

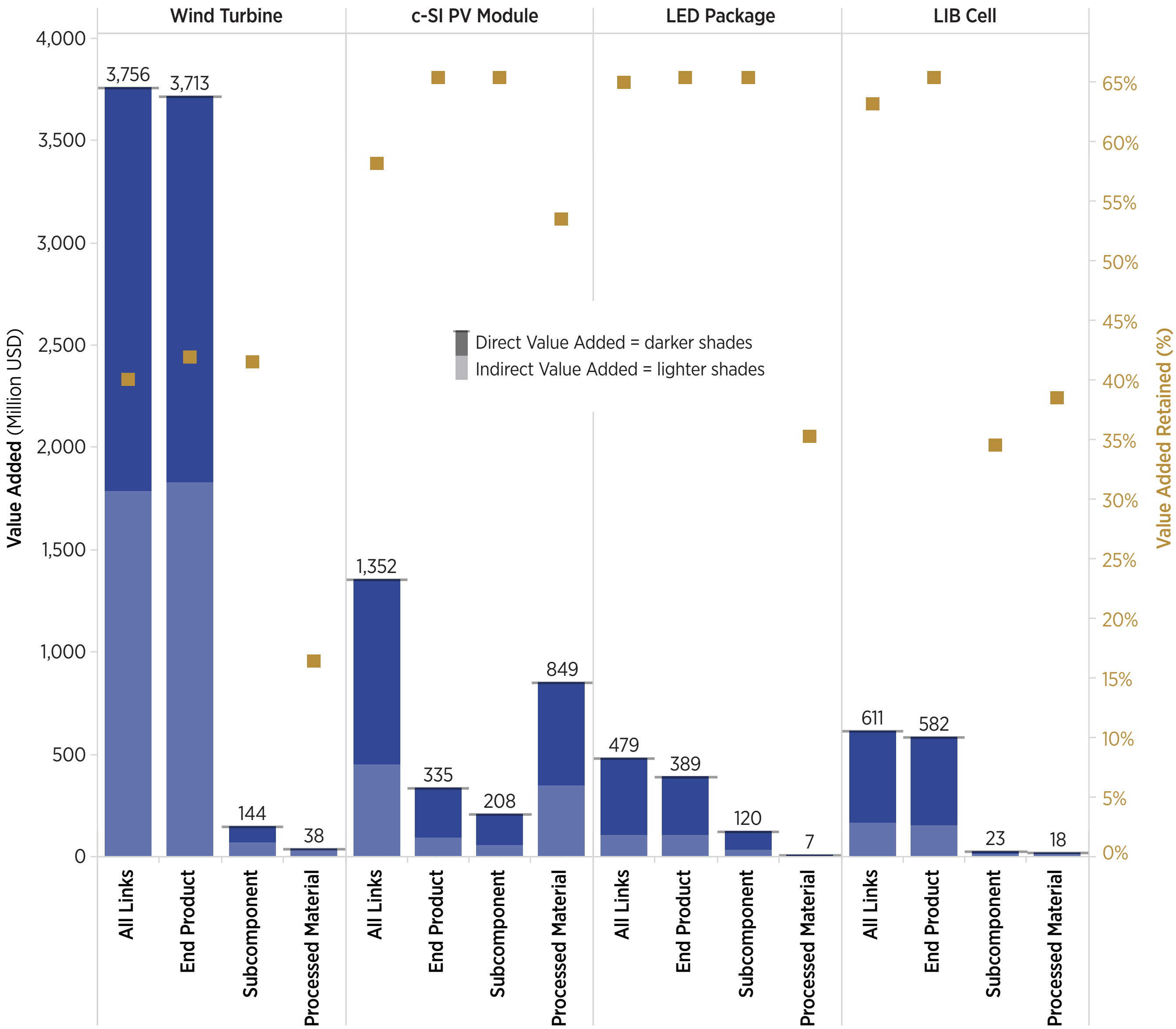


Figure 19-1. U.S. value added (direct in darker shade, indirect in lighter shade, total value added listed on figure) and value added retained (solid squares, right axis) for various clean energy technologies, 2014. See methodology report for data quality discussion.

12 economies. The United States also had the highest percentages across LEDs, PV, and batteries (65%, 58%, and 63%, respectively) and its 40% in wind trailed only the UK (46%) and Canada (44%).

When including indirect with direct value added retained, the United States, with 80%, trails only Brazil. As with direct value added, direct and indirect value added retained is highest in the United States for c-Si PV, batteries, and LEDs (87%, 87%, and 82%, respectively). In wind, the United States retains 76% total value added, behind only Brazil and Japan.

Compared with the other economies in this report, United States industries import fewer inputs as a portion of revenue (5% compared to the 11% average) and have high percentages of value added retained (55% compared to the 46% average). This pushes total value added levels higher relative to production revenue. In the case of the United States, clean energy manufacturing has relatively high value added, which pushes the direct value added numbers up. Value added from indirect impacts from clean energy manufacturing is not as significant. Combined with direct, this drops the United States to third among economies in this report when divided by production compared to first for direct value as a portion of production. The clean energy manufacturers themselves are more significant in terms of GDP contributions than their supply chains.

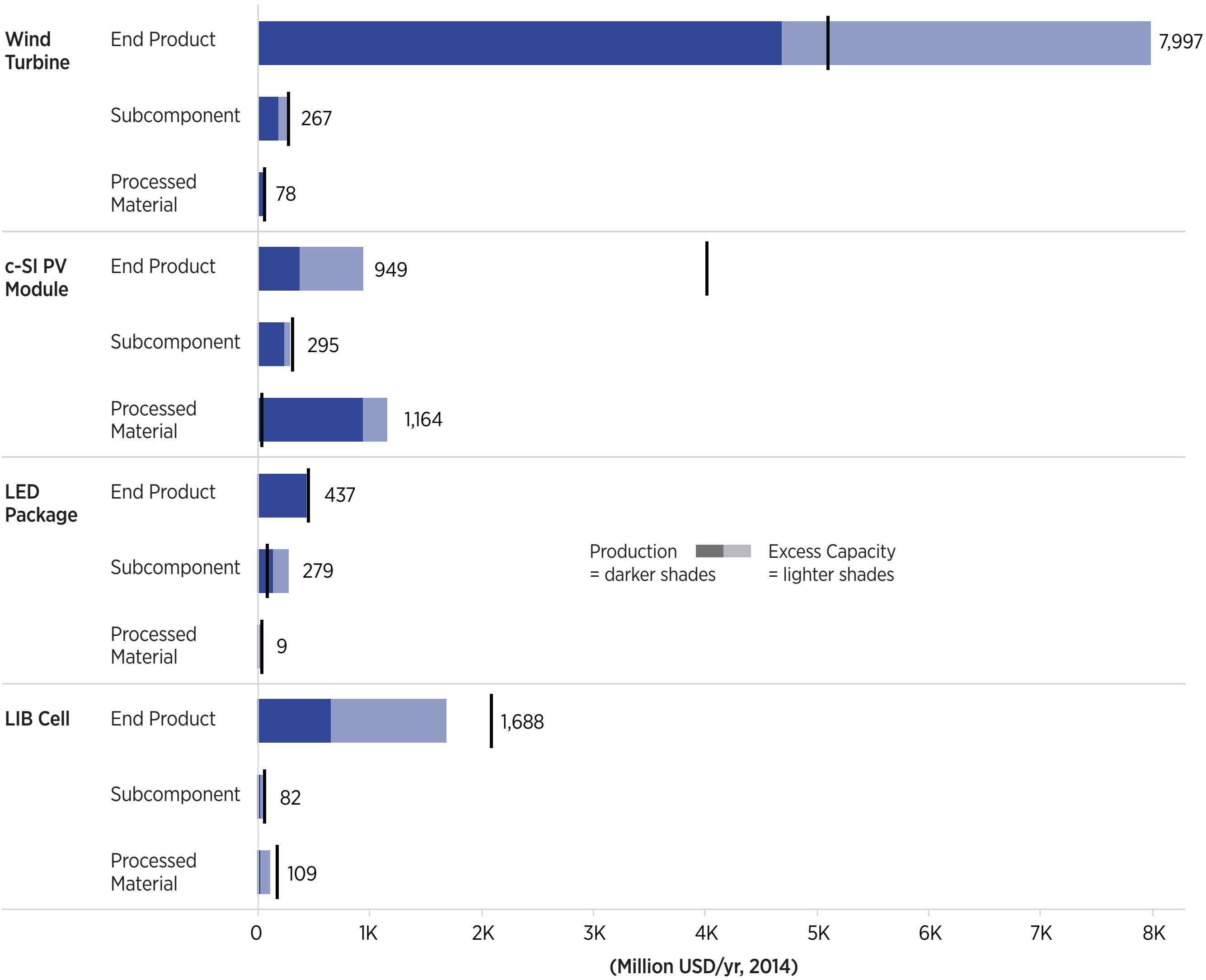


Figure 19-2. U.S. demand (line), production (dark shading), and manufacturing capacity (total labeled in figure, light shading indicates excess capacity) for various clean energy technologies (for LED packages, assumed production equal to demand due to lack of demand data), 2014. See methodology report for data quality discussion.

Manufacturing Landscape: Demand, Manufacturing Capacity, and Production

In 2014, the United States manufacturing sector contributed 12.1% to national GDP, up from 12.0% in 2009,[58] at 2.2 trillion USD. Manufactured goods were 86% of exported goods from the United States. The primary U.S. manufacturing sectors are steel, automobiles, and products from petroleum. In the clean energy space, demand is driving domestic manufacturing of clean energy technologies and components, particularly of wind turbine components. For example, wind industry clusters have formed in Colorado, Michigan, and other states due to proximity to demand, labor conditions, and state and local support mechanisms.

As of June 2016, 20 states and Puerto Rico have implemented clean energy manufacturing support policies to recruit or cultivate the manufacturing and development of renewable energy systems and equipment (DSIRE 2016). These incentives consisted mostly of tax credits, tax exemptions, loans, and grants. Most of the incentives apply to several renewable energy technologies, but some states targeted specific technologies.

In 2014, the United States was a global leader in manufacturing nacelles, blades, towers, and generators for wind turbines; and home to a strong manufacturing base for polysilicon for c-Si PV modules, and Li-ion battery cells and electrolytes. Figure 19-2 shows the 2014 U.S. manufacturing capacity, production, and demand for the four technologies included in this analysis.

In 2014, the United States hosted 9,000 MW of wind nacelle annual manufacturing capacity (10% share of the global total), 6,200 MW of blade capacity (7% share), 5,500 MW of tower capacity (9% of global), and 5,000 MW of generator capacity (10% of global). The United States is second among economies studied in this analysis for manufacturing capacity for towers, and ranks third for generators, nacelles, and blades. The United States has an established position in polysilicon manufacturing, hosting 12,700 MW (17% share) of annual manufacturing capacity in 2014. Domestic annual manufacturing capacity of other segments of the c-Si PV supply chain is lower: 1,300 MW of module (2% share), 550 MW of cell (<1% share), and 400 MW of wafer (<1% share) capacity. In 2014, the United States was home to a small share of LED-related manufacturing capacity, including 4.7 billion packages/yr of LED packages (3% share), 6.3 billion packages/yr of LED chips (4% of global), and 2.3 billion packages/yr of sapphire substrate (<1% share). The United States was home to 4,600 MWh of Li-ion battery cell (20% of the global total), and 3,800 MWh of electrolyte (19% of global) manufacturing capacity in 2014. Upstream Li-ion material and component manufacturing was also represented, with the United States hosting 400 MWh of cathode (2% of global), and 3,100 MWh of separator (8% of global) manufacturing capacity in 2014.

United States manufacturing utilization rates are generally below global averages. United States PV module manufacturers achieved an average utilization rate of 40%, below the global average of 55% for the other economies included in this analysis. United States Li-ion cell manufacturers averaged 39%, just below the global average 41% for Li-ion cells.

On the demand side:

- United States demand for wind turbines has rebounded since a slump in 2010–2011. In 2014, annual U.S. wind turbine demand was 4,900 MW. GE, Siemens, and Vestas supply 98% of the turbines for the U.S. market.
- The United States has emerged as a leading demand market for c-Si PV modules, accounting for 5,600 MW of annual demand (15% of global demand) in 2014. The United States was the third-largest demand market for PV in 2014 (behind China and Japan), and is expected to be the second-largest demand market in terms of cumulative installations between 2015 and 2020 (NREL estimates using data from BNEF 2015, James 2015, Labastida and Gauntlett 2015).
- In 2014, the United States was the largest single demand market for LDV Li-ion cells (5,700 MWh or 60% of total global demand). U.S. demand was driven by domestic EV manufacturing facilities and associated battery pack assembly. The United States was also second-largest demand market (behind Japan) for electrified light duty vehicles in 2014.

58. BEA, http://www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=51&isuri=1&5114=a&5102=5

Trade Landscape: Balance of Trade and Trade Flows

The United States has an open trade policy and conducts the majority of its trade under WTO's "most favored nation" treatment; approximately 22% of imports enter through free trade agreements or bilateral preferential regimes. Primary markets for all U.S. manufactured goods are Mexico and Canada due to proximity and free trade agreements like NAFTA. The United States is the world leader in trade related to intellectual property (IP), with royalties and license fees comprising 43% of the global total in 2012 (WTO 2014b).

Two major policies promote the export of renewable energy technologies. First, the Renewable Energy and Energy Efficiency Export Initiative (RE4I) began in 2010 and seeks to increase U.S. exports by setting up unique financing options and by establishing semi-annual trade missions to negotiate lower trade barriers with target economies (ITA 2016b). Second, an environmental technologies initiative provides information and supports collaboration to boost exports of environmental products, including clean energy technologies (ITA 2016b). According to the International Trade Administration (ITA) market report, U.S. clean energy exports are likely to increase in the coming years. ITA expects that Canada, Japan, and India will be the top three markets for U.S. renewable energy exports (ITA 2016a).

The United States has erected trade barriers against certain clean energy technologies. The United States has imposed anti-dumping and countervailing duties on Chinese PV cells, with total duties ranging from 22% to almost 260%. Anti-dumping/countervailing duties also are levied against Chinese and Vietnamese wind tower manufacturers, again to counter government subsidies. China imposed duties on polysilicon from the United States.

Figures 19-3 through 19-7 show U.S. balance of trade in the selected clean energy technologies both collectively and individually.

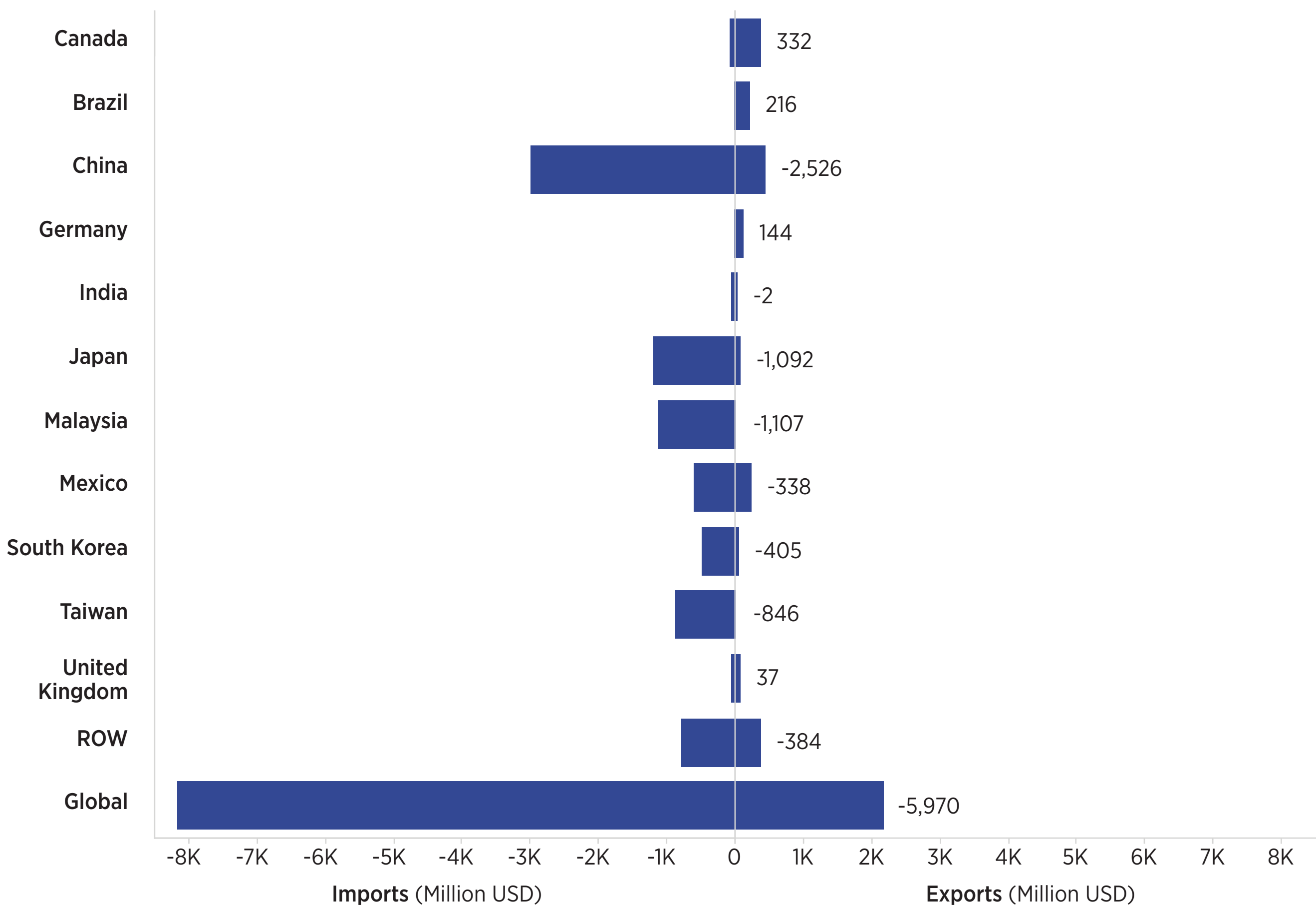


Figure 19-3. U.S. balance of trade aggregated for four clean energy technologies (end products), 2014. Imports shown as negative, exports shown as positive, balance of trade annotated. See methodology report for data quality discussion.

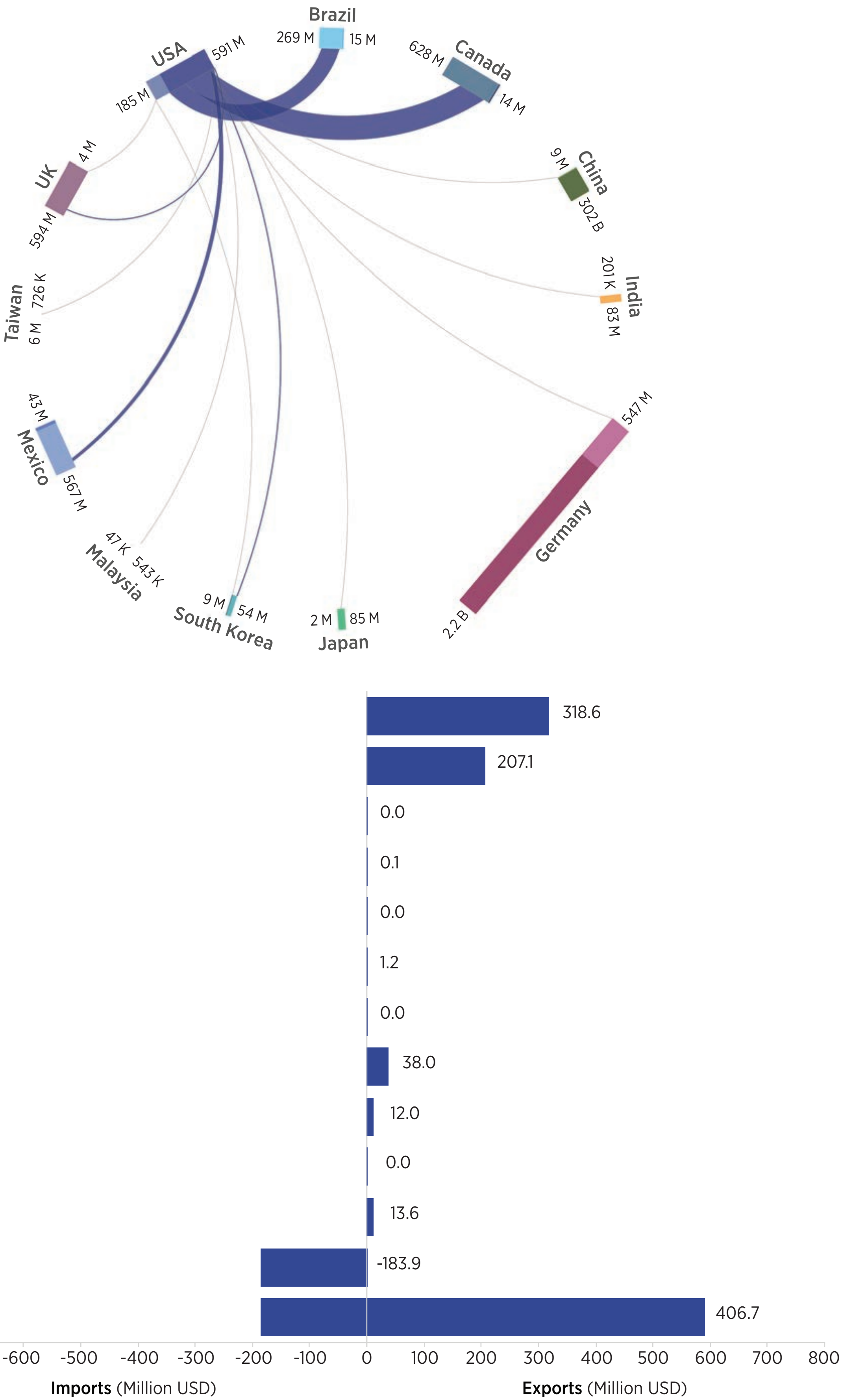


Figure 19-4. Trade between United States and key partners in wind turbine generator sets, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

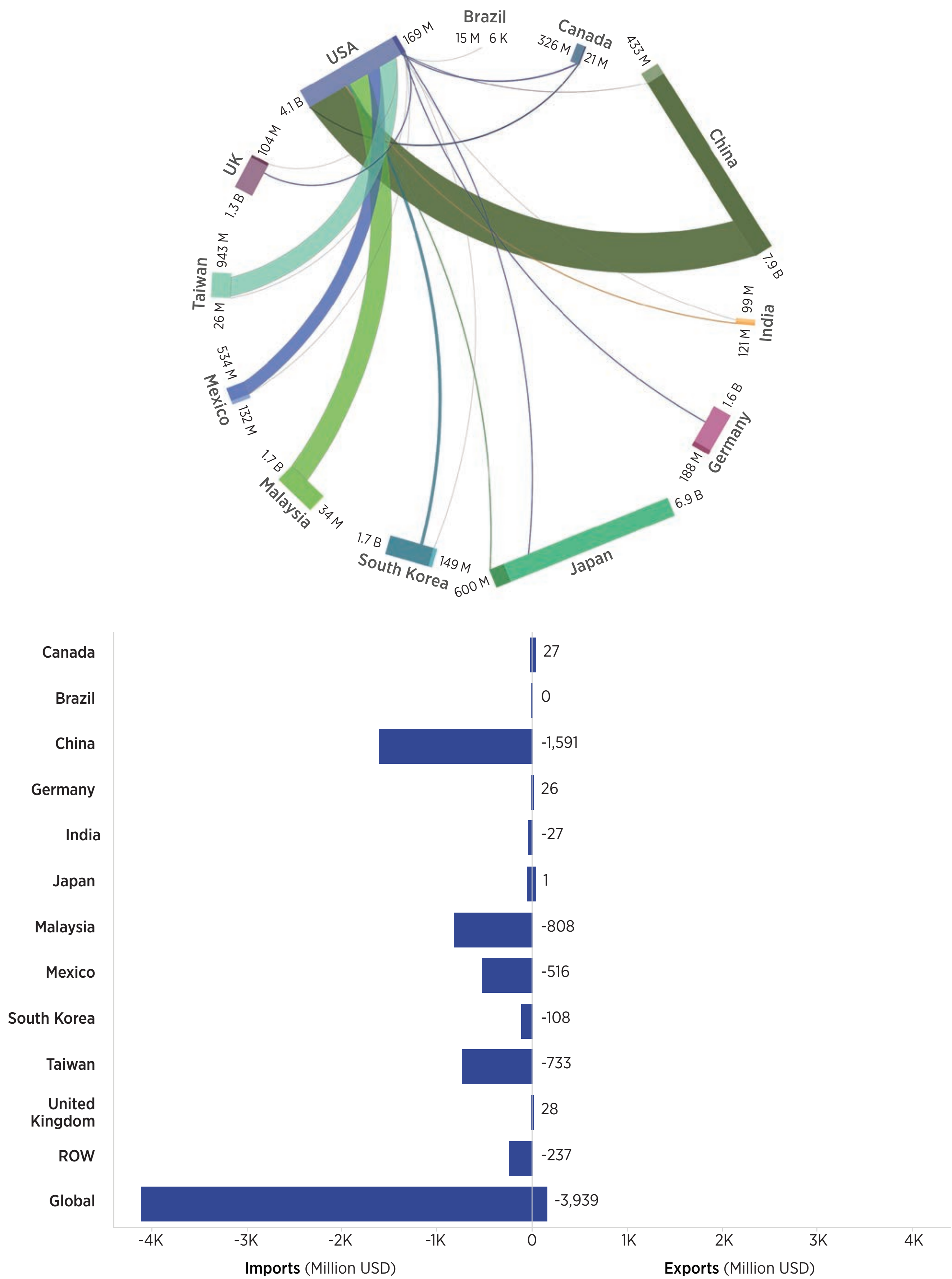


Figure 19-5. Trade between United States and key partners in c-SI PV modules, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

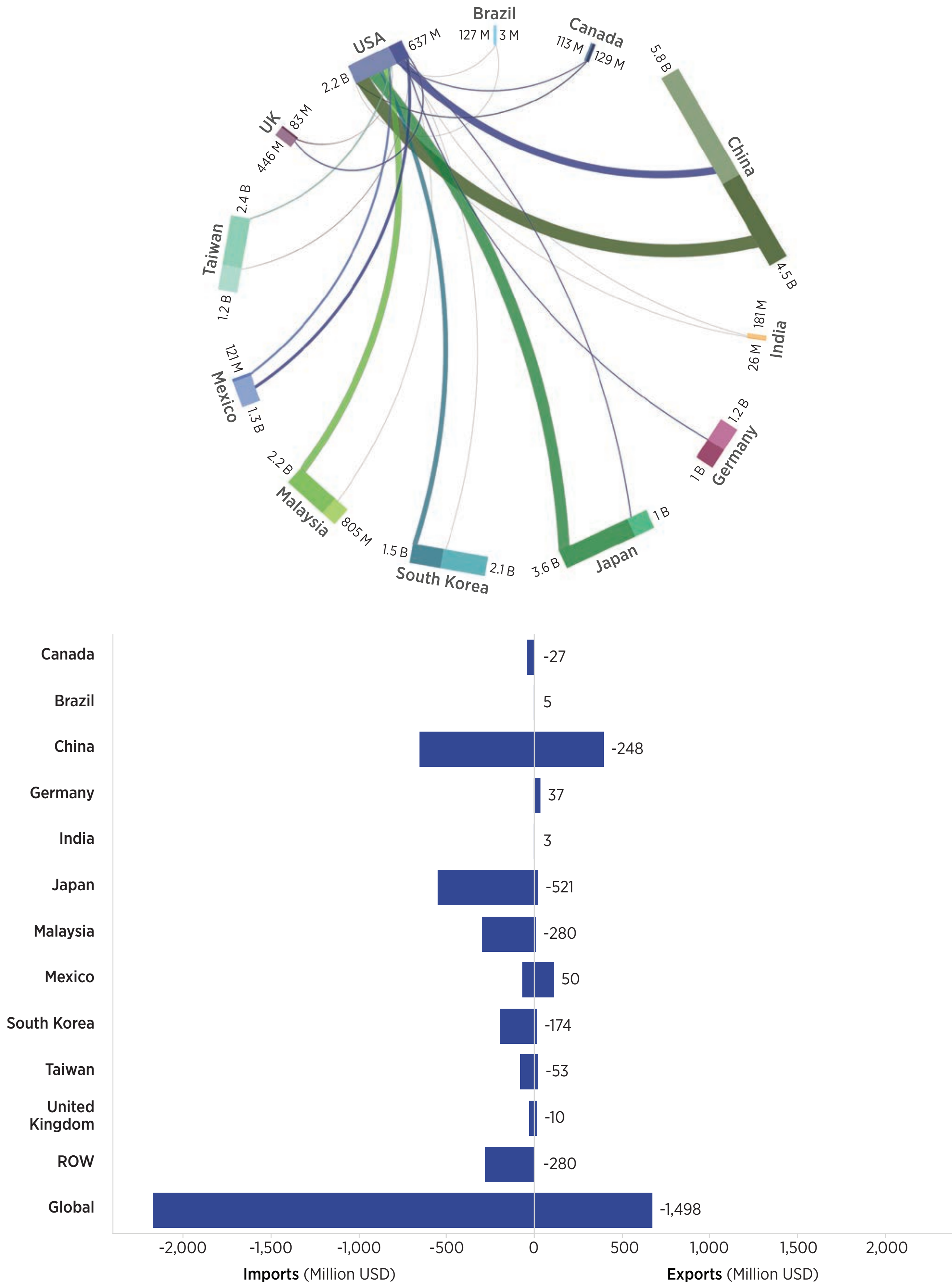


Figure 19-6. Trade between United States and key partners in LED packages, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

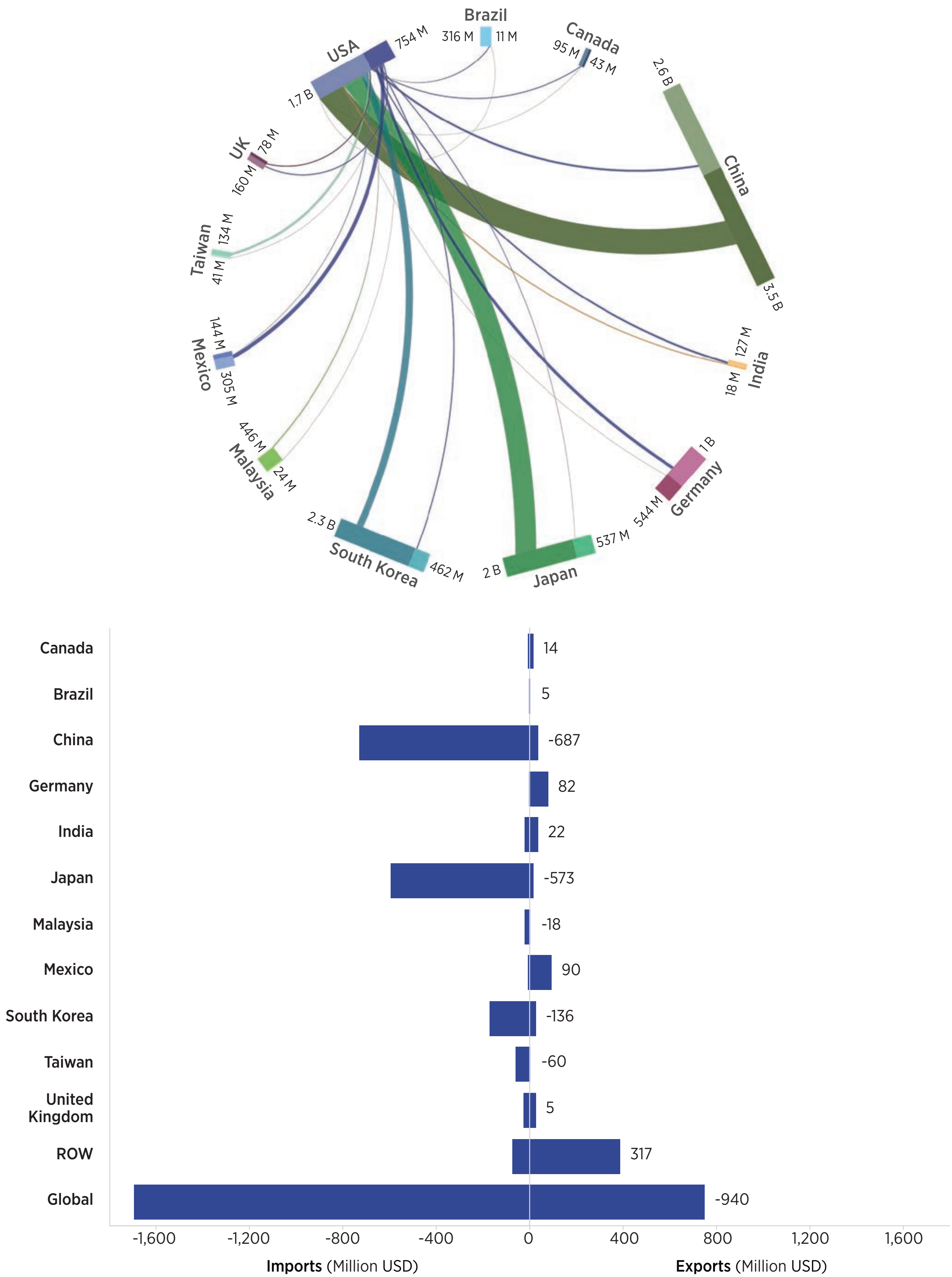


Figure 19-7. Trade between United States and key partners in Li-ion cells, 2014. See methodology report for data quality discussion. Darker shades represent exports; lighter shades represent imports.

20 | Select Emerging Clean Energy Technologies

The clean energy technology sector encompasses a much broader set of technologies than the four covered in this analysis. And new clean energy technologies continue to emerge. Two emerging products have potential to reshape the clean energy landscape: wide bandgap semiconductors and renewable jet fuel. Wide bandgap semiconductors can enable highly efficient power electronics systems, and renewable jet fuel can provide cleaner, biomass-based alternatives to conventional petroleum-based jet fuel.

Manufacturing Wide Bandgap Semiconductors for Power Electronics

Wide bandgap (WBG) semiconductors are a class of materials that can operate efficiently at much higher temperatures, voltages, and frequencies than traditional semiconductor materials (Takahashi, Yoshikawa, and Sandhu 2007). Two leading WBG materials that have been commercialized are silicon carbide (SiC) and gallium nitride (GaN). When employed in power electronic systems, WBG materials have the potential to achieve significant energy savings in industrial motor drives, hybrid and electric vehicles, lighting, data centers, AC adapters, solar inverters, power supplies, and grid control components. Deploying WBG semiconductors could reduce energy usage in power electronic applications by more than 100 TWh/year, or more than 2.5% of U.S. electricity consumption in 2014 (DOE 2015c). Additionally, WBG semiconductors can allow for significant reductions in the physical footprint of power electronic systems, enabling lower balance-of-system cost and potentially opening new markets.

- In 2014, the SiC chip industry was worth about 133 million USD. Power factor correction and photovoltaics (PV) were the leading applications. The GaN device market for power electronics was estimated at 10 million USD in 2015, and currently consists of lower voltage applications than SiC (Lin and Gueguen 2015).
- The markets for both SiC and GaN power electronics are expected to accelerate in the near future; by 2020, SiC and GaN are estimated to reach market sizes of 436 million USD and 300–560 million USD, respectively (Lin and Gueguen 2015).
- Design of WBG devices, packages, and systems is still an active area of development with significant room for innovation around substrate growth, device performance, packaging design and materials, passive components suitable for high temperature and high frequency operation, and overall system design.
- WBG semiconductors currently comprise less than 2% of the overall semiconductor power electronics market, and still face barriers to widespread adoption (Lin 2016).
- The United States is currently the world leader in production of SiC substrates, and also produces a significant fraction of SiC chips and packaged devices. Europe and Japan are also major players in SiC along the supply chain. Manufacturing of semiconductor devices such as WBG tend to have a relatively high value added per unit of production, especially in the United States, Germany, and Japan. Value added divided by gross output is 87% in the United States, 71% in Germany, and 68% in Japan. High value added per unit of production does not indicate where production will occur, as this is influenced by a number of other factors.

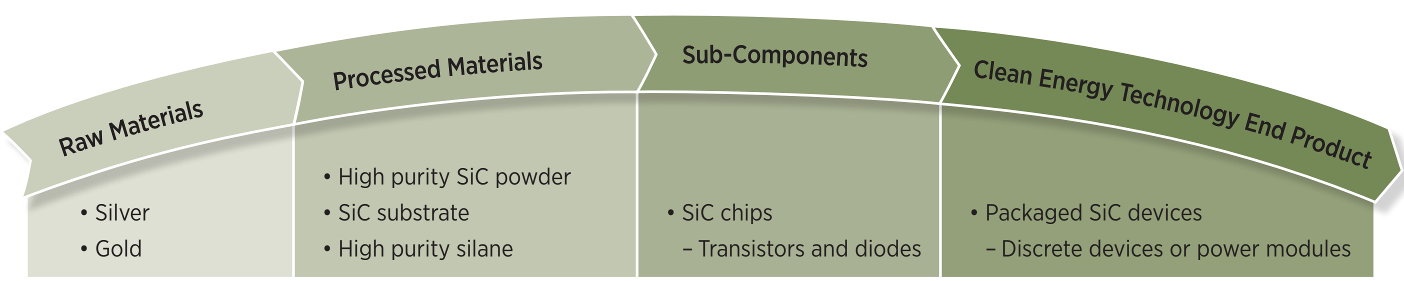


Figure 20-1. Simplified supply chain for SiC products

Specific materials and components listed under each supply chain link were selected based on the benchmark criteria outlined earlier in this report. The clean energy technology end product is ultimately incorporated into other technologies, such as motor drives, to enable energy efficiency.

Manufacturing Value Chain for Wide Bandgap Devices

Figure 20-1 shows an example of a simplified WBG device supply chain for SiC. Raw materials are processed to create precursors required to grow substrates, upon which the WBG chips are fabricated. For power electronics, the chips are either transistors or diodes. Those chips are then placed into packaged devices with leads that can be connected into larger circuits and systems, for example, variable frequency motor drives or PV inverters.

Raw Materials

Very small amounts of silver and gold are often used to make the metal contacts to SiC transistors or diodes. While we do not expect the availability of these raw materials to limit the number of WBG devices that could be produced, raw materials cost is high and can fluctuate dramatically. The largest producers of mined silver in 2014 and 2015 were China, Mexico, and Peru, but significant amounts of production also occurred in other economies around the world. Top gold producers in 2014 and 2015 were China, Russia, Australia, and the United States.

Silicon and carbon are the raw materials used in the greatest volume in SiC chips. These materials are abundant, available globally, and do not pose a supply chain constraint.

Processed Materials

There are several important processed materials that are frequently used in the manufacture of SiC devices, including high purity SiC powder, SiC substrates, and silane. High purity SiC powder is essential for growing quality SiC ingots, and the powder is available from only a few suppliers. These ingots are machined and sliced to create SiC substrates. These substrates contribute significantly to the cost of WBG devices. In 2014, 2015, and 2016, the United States produced the majority of SiC substrates, as well as the substrates with a thin, crystalline layer of SiC deposited over them (which we will refer to as wafers), followed by Europe, Japan, and other Asian economies. China is currently building substrate and wafer capacity in order to develop a local supply chain for these components, and may be poised to disrupt the wafer market over the next several years.

Epitaxial SiC layers are grown on SiC substrates in order to fabricate devices. High purity silane is a critical precursor used for growing these epitaxial layers, and is typically produced by large, international gas companies.

Other processed materials used for SiC packaged devices are either widely available and not critical to cost, substitutable, and/or are traded globally and do not pose supply chain challenges.

Sub-Components

The chips used in SiC power devices are either transistors or diodes. The steps for processing SiC wafers into chips overlap with those required for traditional Si chips. Si foundries could be converted to also allow for SiC production. Most Si foundry facilities are currently located in Asia. DOE is pursuing the conversion strategy with a U.S. plant through its Power America initiative.

Clean Energy Technology End Product

SiC chips can be integrated into a discrete semiconductor package or into a power module, which typically consists of multiple semiconductor chips. We call these the "end product" because they are the enabling clean energy technology that are sold as packaged devices and then integrated into a complete power electronic system. Examples of such systems include variable frequency motor drives, PV inverters, and laptop chargers. Japan has implemented SiC in a diverse range of applications, particularly in rail and electric vehicles.

Manufacturing Capacity, Production, and Trade for WBG Semiconductors

For subcomponents, Japan, Europe, and the United States lead production of SiC chips (bare die). While China currently has very little capacity for making SiC chips, several SiC device fabrication facilities are under development there.

As with chips, almost all production of SiC packaged devices occurs in Japan, Europe, or the United States, with the production split almost evenly between these three economies/regions.

As an early commercial technology, there is relatively little trade and there are no WBG-specific trade codes. We expect trade flows will grow and expand as adoption of the technology increases.

Market Demand for WBG Semiconductors

WBG materials constitute less than 2% of the total power semiconductor market in 2016 (Lin 2016). SiC diodes, which currently make up 80%-85% of the overall SiC power device market, have been available since 2001. The value proposition and reliability of these diodes is increasingly recognized. SiC transistors entered the market five years ago. Lin (2016) identified several barriers for adoption and actions to overcome them, including:

- **High cost and long-term reliability:** SiC costs have declined, but are still high relative to traditional alternatives, primarily due to the high substrate cost and lower yields. SiC is increasingly demonstrating its reliability in the market. GaN power electronics are an emerging alternative. As of this writing, production volumes are low and costs remain high. GaN manufacturing is limited in part because GaN substrates are still under active development and are not available in large volumes. To address cost concerns, suppliers are trying to create more affordable "plug and play" solutions to enable broader deployment of WBG devices.
- **Supply chain issues:** Because only a few companies supply SiC or GaN, it is difficult to multi-source many components. Announced new entrants to the WBG market could alleviate shortages.

Manufacturing Renewable Jet Fuel

Global air passenger travel is expected to more than double in the next twenty years, according to the International Air Transport Association (IATA 2016). Industry and governments are pursuing development of "drop-in" renewable fuels to meet growing demand for air travel while also addressing concerns about fuel costs, global climate, and energy security. After efficiency measures, renewable jet fuel represents the primary mechanism to reduce use of petroleum-based hydrocarbons in the aviation industry. Adoption of renewable jet fuels could potentially reduce life cycle GHG emissions by 55%–70% compared with conventional jet fuel, according to research from DOE's Argonne National Laboratory (Elgowainy et al. 2012). In the Argonne model, renewable jet fuel produced from pyrolysis of corn stover reduced emissions by 55%. Hydroprocessing of soybean or algal oil reduces emissions by 70%. Produced from tallow and plant-based oils or sugars, renewable jet fuels are comparable to petroleum-derived jet fuel, but are currently blended with petroleum fuels to ensure fuel quality.

Interest continues to grow in domestic production of renewable jet fuel (Haq 2016). The European Union aims to have the aviation industry use 0.5 billion gallons by 2020 (European Commission 2016b). Longer-term, the International Air Transport Association is calling for a 50% reduction in GHG emissions by 2050 relative to 2005 (IATA, n.d.). Expansion may be constrained by availability of sustainable feedstocks. Cellulosic and algal feedstocks could be tapped to overcome potential cost and supply limitations of current oil seed crops (DOE 2011).

Renewable jet fuel is in a pre-commercial, testing phase with multiple process technologies in development. Approximately 1.1 million gallons of renewable jet fuels were produced in 2014. The United States and Europe led production. The bulk of renewable jet fuel is used in research and development functions, and little to no trade in renewable jet fuels occurs. With at least seven production processes in development, renewable jet fuel is a very active area for innovation as manufacturers compete using a variety of technological approaches (Mawhood et al. 2014).

Manufacturing Value Chain for Renewable Jet Fuels

Renewable jet fuel is manufactured in a chemical production process, rather than in a fabrication or assembly process. In 2014, manufacturers used two processes to generate renewable jet fuel for commercial flight testing:

- Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK), which uses oils from a variety of sources
- Hydroprocessed Fermented Sugar-Synthetic Isoparaffins (HFS-SIP), in which sugars are fermented by yeast to farnesene, an unsaturated C15 hydrocarbon.

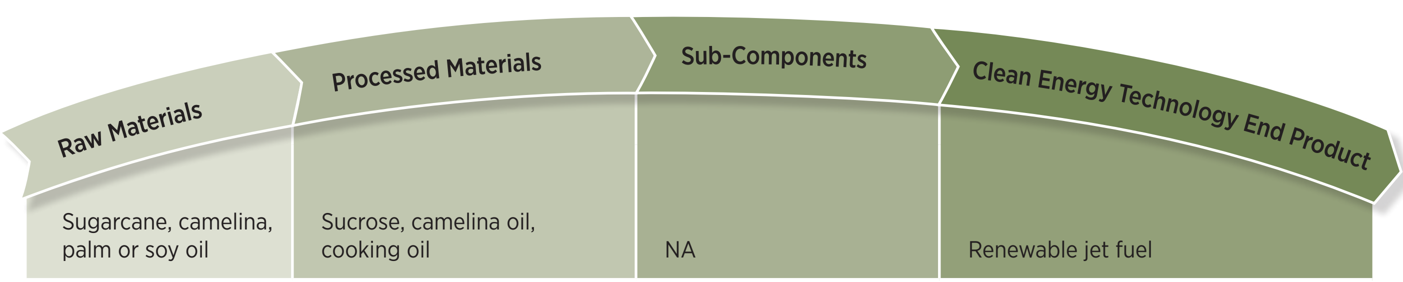


Figure 20-2. Simplified supply chain diagram for the HEFA-SPK process of manufacturing renewable jet fuel.

The farnesene is reacted with hydrogen to produce farnesane, a saturated, branched hydrocarbon.

We describe the manufacturing of HEFA-SPK as an illustration of renewable jet fuel manufacturing along supply chain (Figure 20-2).

Raw Materials

Oils from plant and animal sources are the feedstock for the HEFA-SPK process. With the exception of palm oil in the European Union and tallow imports to Singapore, most feedstocks are grown and upgraded regionally. Palm oil is primarily produced in Indonesia and Malaysia (Kurki et al. 2010). HEFA fuel producers are pursuing alternative feedstock to palm oil to help address concerns about deforestation and disruption of animal habitats caused by palm oil production. Alternatives include waste cooking oil, non-edible oil from corn ethanol plants, camelina oil, and algal oils.

Processed Materials

Oils from tallow and plant-based sources are converted to hydrocarbon fuels in two stages. First, the oils react with hydrogen at elevated temperature and pressure with a catalyst. This removes oxygen and saturates any double bonds in the feedstock. Next, the hydrocarbon intermediates isomerize and crack to produce a blending component with properties similar to petroleum-derived jet fuel.

End Product

The HEFA-SPK process generates a mix of branched paraffinic hydrocarbons which closely matches the composition of jet fuel. This mix has been approved for blending with petroleum jet fuels in ratios of up to 50%.

Manufacturing Capacity, Production, and Trade

Renewable jet fuel is in the pre-commercial phase, with potential expansion driven by policy and market efforts to reduce emissions and dependence on petroleum-based jet fuel. HEFA production can leverage existing petroleum refining equipment. Tallow and plant-based oils can be blended with petroleum and co-processed in a modified hydrotreating unit in a refinery. One company in Sweden co-processes tallow oil blended up to 50% with petroleum for the diesel market. Other companies have converted existing petroleum refineries into dedicated HEFA refineries (IATA 2014). Table 20-1 lists the key manufacturers of renewable jet fuels and their production in 2014.

Because renewable jet fuel is still pre-commercial, trade of the fuel is not yet significant. Some of the raw materials are traded as industrial or food products. It is expected that the development of robust supply chains of sustainable materials will be a significant requirement for the renewable jet fuel to become fully commercial.

Market Demand for Renewable Jet Fuel

Global production of petroleum-based jet fuel has held steady at around 83 billion gallons per year, and the United States produces around 22 billion gallons per year (EIA 2016). Demand for renewable jet fuels is now largely driven by research and development needs. The International Air Transportation Association estimates that 26 billion gallons of renewable jet fuel will be needed by 2050 to meet their goal of reducing carbon emissions by 50% relative to 2005 (IATA 2015).

Table 20-1. Key Renewable Jet Fuel Companies and Production in 2014

Company (Headquarters)	Location(s)	Process	Feedstock	2014 Production Volume (M gallons)	Testing/Use
Neste (Finland)	Poorvo, Finland; Rotterdam, Netherlands; Singapore	HEFA	Used cooking oil, palm oil, rapeseed oil, tallow	1.1 MM gallons RJF (Total capacity of 671 MM gallons combined RJF and diesel)	
Amryis/Total (Brazil)	Brazil	HFS-SIP	Local sugarcane	Capacity of 13 MM gallons RJF per year	Used at 10% blend in two commercial flights in 2014
ENI (Italy), Preem (Sweden), Green Energy Products (KS, USA), REG Synthetic Fuels (LA, USA), Diamond Green Diesel (LA, USA)		HEFA	Oils	Variable – all have capability to produce RJF	
Boeing	Partnership in China	HEFA	Used cooking oil	In discussion	

Data from ASTM 2016a, ASTM 2016b, Rumizen 2013.

Conclusion

The current state of clean energy trade reflects the cumulative dynamics of a high-growth decade in which both markets and manufacturing have grown significantly within an increasingly complex set of policy environments. Strong domestic markets have not necessarily been supplied by domestic manufacturing, particularly markets for those technologies that benefit from economies of scale and where incentives for manufacturing investment or output have been adopted, and markets for technologies where transportation was not a determining factor for manufacturing location, such as PV modules, Li-ion battery cells and LED packages.

The U.S. situation is notable, as clean energy markets have been particularly strong and are served by both domestic and imported end products. The United States is one of the top five manufacturing economies globally and retains the highest amount of manufacturing value added of the technologies evaluated. Even though the United States is a net importer to meet its large demand for the technologies evaluated, some U.S. clean energy technology manufacturers are net exporters of components upstream in the supply chains. China stands out as an example where policies have been implemented to support both domestic markets and the expansion of domestic manufacturing to serve both domestic and export markets. In Japan, both these situations are apparent for specific technologies: the country's strong domestic market for PV modules is served with significant imports, while its LED package manufacturing serves both its domestic and export markets.

For the clean energy technologies covered in this report and many others, technology innovation is anticipated to continue to drive relatively rapid turnover of technologies and associated manufacturing capacity. Such innovation creates significant opportunities to attract manufacturers that can serve domestic markets, compete effectively in other markets, and displace incumbent technologies.

Manufacturing is a global enterprise that changes in response to market forces and advances in equipment, processes, and materials. In our analyses for this report and our detailed sector reports, we have noted several important trends in manufacturing that represent a qualitative benchmark of where manufacturing is headed in the coming years.[59] Identifying these trends will help focus future benchmarking analysis to better understand the market drivers, both policy and economic, for the dynamics in clean energy technology manufacturing.

First, deeper knowledge of supply chains enables nuanced decisions related to manufacturing locations for extracting and processing raw materials, making the array of required subcomponents, and assembling the final product. This more robust knowledge, in turn, can help set research agendas and determine investment strategies optimized by location and technology. When processed materials through subcomponents to final product are accounted for, the path of manufacturing these clean energy technologies often traces the globe. While one economy may lead in the manufacturing of a final end product, other economies may gain significant value providing materials and subcomponents to that product.

Second, clean energy technology manufacturing is in the midst of a revolution. New processes such as additive, on-demand, and onsite manufacturing enable the making of products to become decentralized and distributed. This could mean that small businesses and even individuals, in communities of any size, would have the ability to make complex products themselves, which could result in democratization of technology and manufacturing.

Third, the trends toward increasingly global supply chains and decentralized manufacturing can create tremendous opportunities for innovation and economic development in the United States and the world. These opportunities include developing new dynamic industrial processes, sustainable materials, and advanced clean manufacturing technologies.

Looking ahead, in addition to producing our technical reports, we plan to update these benchmarks to track trends in clean energy technology manufacturing. Key actions will be developing and utilizing new data sources, adding important new technologies, and engaging with decision makers to use and improve these benchmarks. We look forward to discovering and following trends in clean energy technology manufacturing and continuing to provide objective analysis, unique data sets, and robust insights in future reports.

59. Text in this section published in similar form in Engel-Cox (2016).

Glossary

Clean energy technologies: Clean energy technologies as those that produce energy with fewer environmental impacts than conventional technologies, or that enable existing technologies to operate more efficiently, consuming fewer natural resources to deliver energy services. Clean energy technologies may include renewable energy, clean non-renewable energy, and energy efficiency technologies for electricity generation, fuel production, and sustainable transportation.

Clean energy technology end product: The end product is the finished product of the manufacturing process, assembled from subcomponents, and ready for sale to customers as a completed item. Clean energy examples include PV modules and LED luminaires. In this link of the supply chain, value added comes from assembling subcomponents into a marketable product that customers value.

Clean energy technology manufacturing: Manufacturing of clean energy products (renewable energy, sustainable transportation and energy efficiency technologies) and improving manufacturing across the board by increasing energy productivity and low-cost domestic fuels and feedstocks.[60]

Direct value added: Value added from the output of the sector in question. For example, if solar module manufacturing pulled in 100 million USD in revenue in a specific economy and 70% of that went to intermediate inputs, then direct value added would be the remaining 30%.

Final demand (FD): Demand for what is produced by an industry that is not an input for some other product. This demand can come from households, investors, governments, and the rest of the world through net exports. Final demand is also a measure of GDP.

Gross output: Gross output is sum of VA and all payments for intermediate inputs. This is a measure of overall economic activity. Gross output is final demand plus intermediate demand or intermediate demand plus value added.

Indirect value added: Value added that is supported by the domestic intermediate expenditures made by the sector in question. This is a comprehensive figure that captures all supply chain activity necessary to support the output of the sector in question within the economy in question. Indirect value added from solar module manufacturing in China, for example, would not include polysilicon that is imported from the United States—this is estimated separately.

Intermediate Inputs: Intermediate inputs are payments by a business or industry to other businesses and industries for goods or services used in production.

Manufacturing capacity: Amount of product that can be produced in a given time period by existing physical plant and other necessary infrastructure (e.g. megawatts of PV modules per year). **Production** is the actual amount of a product produced, also normalized to a given time period. Manufacturing capacity and production together reflect supply. Capacity and production, in combination with market size and growth, are the basic metrics used in assessing the supply, demand, and trade flow dynamics occurring within an industry.

Manufacturing supply chain: A supply chain is a complex and dynamic supply and demand network consisting of an integrated system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities involve the procurement, transformation and logistics of natural resources, raw materials, and components into a finished product that is delivered to the end customer.

Manufacturing value chain: The value created in each step of the supply chain though the key activities that companies do to bring a product from its conception to its end use. Value chain activities can produce goods or services, include a single company or span multiple companies, and occur within a single geographical location or spread across economies. While the supply chain tracks the flows of raw materials and intermediate products to customers (upstream to downstream), the value chain tracks the demand and cash flows from customers to companies (downstream to upstream).

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60. Definitions drawn from DOE (2015).

Market size: Estimate of the demand for a specific product or service, and is typically expressed in units of product volume (e.g. megawatts of PV modules) and in terms of monetary value (e.g. USD). The latter expression of market size accounts for both demand volumes and selling prices. Market size serves as a core metric of demand development and growth over time, and is a key measure of the relative importance of an industry within economies and across the globe.

Processed materials: A processed material is a material that has been transformed or refined from a basic raw material as an intermediate step in the manufacturing process. Processed materials include steel, glass, and cement. In this link of the supply chain, value added comes from processing raw materials into precursors that can be more easily transported, stored and used for downstream subcomponent fabrication.

Raw materials: A raw material, or unprocessed material, is a basic material, mined, extracted or harvested from the earth. Examples include raw biomass and iron ore. In this link of the supply chain, value added comes from extracting, harvesting and preparing raw materials for internationally marketing in substantial volumes.

Social accounting matrix (SAM): A matrix that contains economy-wide data for value added, final demand, intermediate inputs, and gross output.

Subcomponents: A subcomponent is a unique constituent part or element that contributes to a finished product. Clean energy technology examples include generation sets for wind turbines and crystalline silicon wafers for c-Si PV modules. Note that what is a component to the manufacturer may be considered the finished product of their supplier. In this link of the supply chain, value added comes from fabricating processed materials into subcomponents that can then be assembled (with other subcomponents) into end products.

Technical coefficients: Intermediate inputs as a portion of output for each industry. When all technical coefficients are combined in a matrix, this is referred to as the **direct requirements** matrix.

Trade flows: Trade flows are the buying and selling of goods and services between economies. Trade flows measure the **balance of trade**, i.e., the amount of goods that one economy sells to other economies (exports) minus the amount of goods that an economy buys from other economies (imports).

Value added (VA): The VA of an industry, also referred to as gross domestic product (GDP)- by industry, is the contribution from a private industry or government sector to overall GDP. VA consists of labor payments, gross operating surplus, and taxes and can be a measure of GDP. Labor payments are all payments to workers, including benefits. Gross operating surplus is a property-type income that includes payments for capital (including depreciation) and payments to investors. Profits are included in a gross operating surplus. Taxes are net payments to or from the government. If subsidies paid to an industry from the government are greater than taxes paid by that industry to the government, then taxes will be negative.

Value Added Retained: A measure of an industry's contribution to GDP per unit of production. Value added retained is calculated by dividing manufacturing value added by production revenue. High wages and larger economies tend to retain higher levels of value added, as more inputs can be sourced domestically and workers are paid higher wages.

Wind generator sets: CEMAC defines wind generator sets as assembled nacelles shipped with blades

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Appendix A: Economic Fundamentals as Context for Clean Energy Manufacturing Benchmarks

Differences between economic fundamentals (such as GDP, imports, and economy-wide value added) drive some of the differences that appear in our economy-specific analysis of clean energy manufacturing value added.

Gross Domestic Product (GDP)

The economies in this report vary considerably in size. For example, the United States and China have much larger economies than Malaysia and Taiwan (Figure A-1).

In addition, the contribution of the overall manufacturing sector to national GDP varies across economies.

From an economy-wide perspective, value added is the value of production. It is the portion of revenue that goes to GDP—payments to workers, taxes less subsidies, and property-type income[61] such as profits or returns on investment. It is revenue less payments for inputs such as raw materials and business-to-business services.

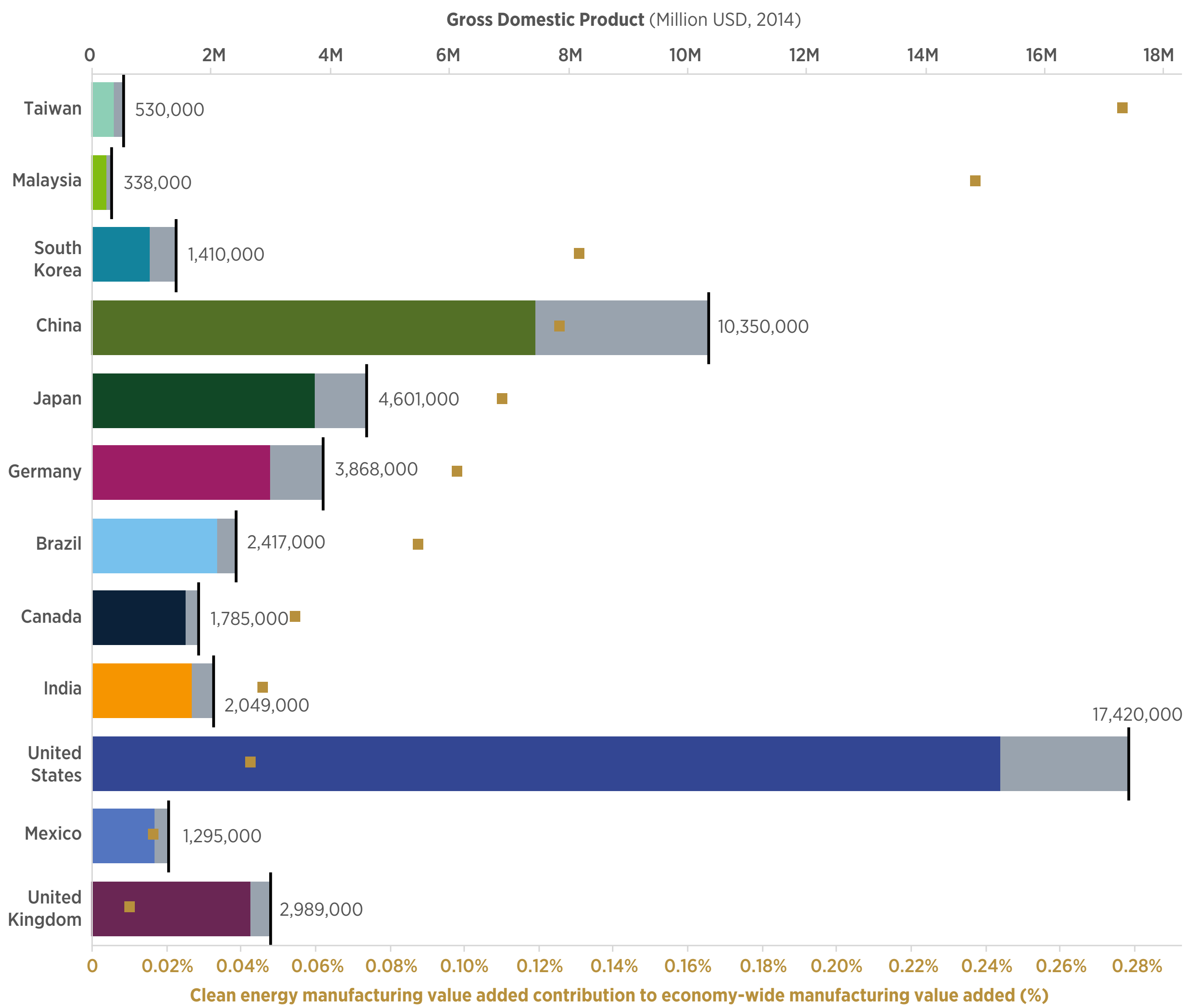

Figure A-1. 2014 GDP and manufacturing sector contribution to GDP by country

61. Property-type income, also known as gross operating surplus, is a company's revenue less what it pays to its workers, what it pays in taxes less government subsidies that it receives, and less the amount that it pays to other businesses for the goods and services that it consumes in order to manufacture its products. It includes profits and proprietor income. Property-type income is not a measure of profitability because it also includes a number of other payments or costs such as costs from capital losing its value or becoming obsolete and payments that companies make for intangible goods or services such as insurance or fees.

The economy-wide value added is affected by imports used in production. Higher portions of imports drive down value added per dollar of revenue within the economy in question. If a business buys an input such as steel from domestic producers, for example, value added from this steel production accrues domestically. If the business imports steel, value added from that steel production accrues to the source economy. Figure A-2 shows the percentage that value added and imports comprise of production across all industries, economy-wide, for the 12 economies included in the benchmark report.

When expenditures on imported inputs are low, the value of these inputs accrues within the economy in question. Conversely, when these inputs are imported they accrue outside of the economy in question and are not included in this report. Differences in expenditures on imported inputs can be explained, in part, by differences in GDP size. Producers in the United States and China have more domestic options for inputs because their economies are large, whereas producers in Malaysia and Taiwan have fewer options because their economies are smaller.

Increased or decreased levels of production could affect economies differently. In the United States, for example, where value added per dollar of revenue is relatively high and expenditures on imports are relatively low, 1 billion USD in production would likely support higher levels of domestic value added than the same dollar value of production would produce in an economy where value added is relatively low and imported inputs are relatively high.

Value added and import percentages do not explain why levels of production differ between economies. Factors influencing production levels can include prices, currency strength, domestic polices, taxes, or subsidies. For example, labor-intensive production may cost less in Malaysia than the United States even though value added per dollar of revenue is higher in the United States. If U.S. production increased, value added would increase, but the U.S. producer would have to charge higher prices and may find it difficult to compete with producers in Malaysia. Higher prices also typically cause consumption of products to decrease, so the dynamics of how changes in production would affect economies extend beyond value added and imports per unit of production.

This, in part, explains why Malaysia and Taiwan import more inputs than the United States and China. Producers in the United States and China have more domestic options for inputs because their economies are large, whereas producers in Malaysia and Taiwan have fewer options because their economies are smaller.

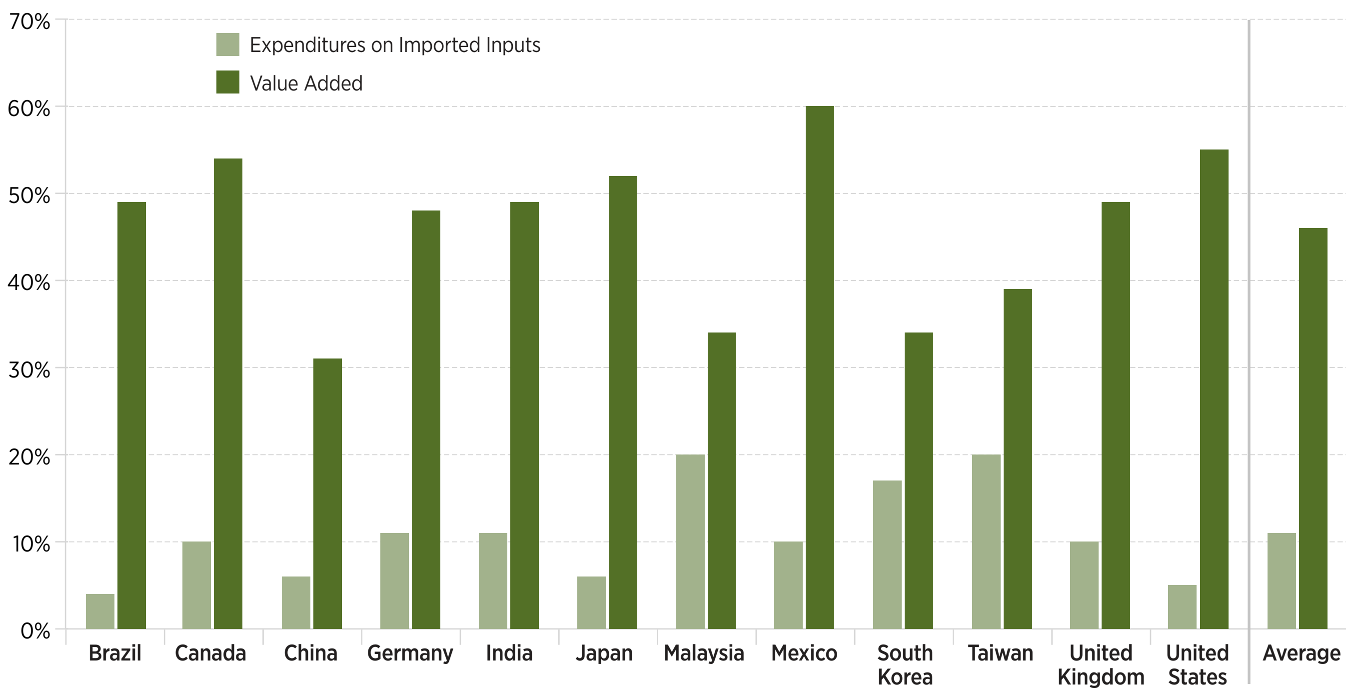

Figure A-2. Imported inputs and value added across all industries as a percentage of gross output. Source: OECD STAN 2015

Using Economy-wide Metrics to Frame Clean Energy Manufacturing Value Added Benchmark Results

These economy-wide metrics provide context for understanding the differences in the clean energy manufacturing value added results across economies and technologies.

- Comparing the *direct clean energy manufacturing value added with national GDP* provides an indication of how clean energy manufacturing compares to the size of the overall economy. Figure A-3 shows total clean energy manufacturing value added as a portion of GDP for each economy. Despite lower levels of production than China and Japan, clean energy manufacturing contributed a greater portion of GDP in Taiwan, Malaysia, and South Korea. Production in China was high and clean energy manufacturing was an above average (unweighted) portion of GDP when compared with other economies.

Despite these different relative significances, manufacturing of c-Si PV, LEDs, wind components, and Li-ion batteries for vehicles composed less than 1% of GDP in each economy studied. This does not indicate that these industries are unimportant. The direct value added figures do not include domestic supply chains that rely on clean energy manufacturers. The figures also obscure international linkages. Consultancies that contribute to GDP in Germany may rely on PV module manufacturers in Taiwan, for example.

- Comparing the *total direct and indirect value added of clean energy technologies with production revenue from manufacturing clean energy technologies* provides

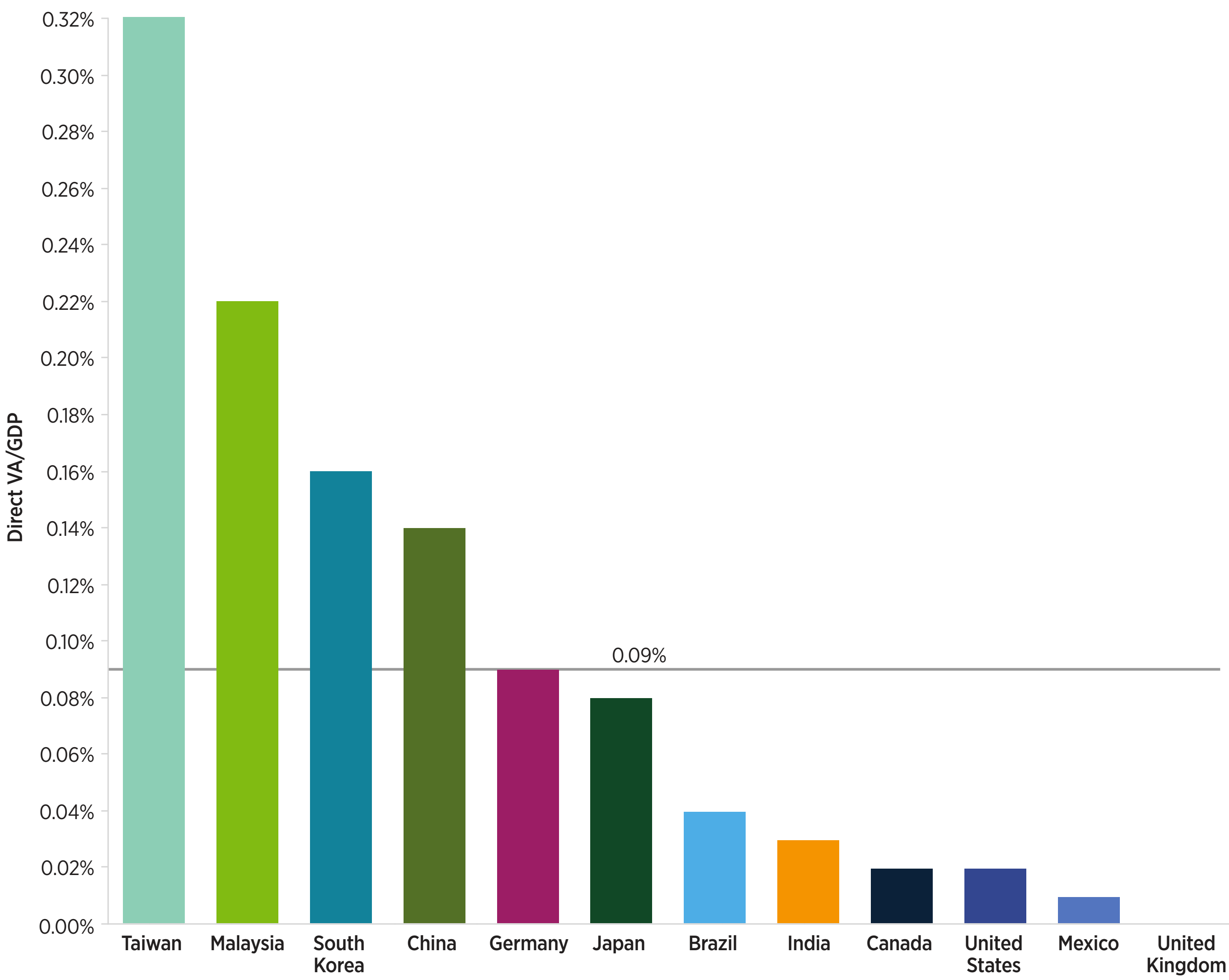

Figure A-3. Clean energy manufacturing direct value added as a portion of GDP an estimate of how much each nation's economy retains from manufacturing clean energy technologies. Total value added retained varies across economies as a result of different wage rates, different tax rates, government subsidies to industries, and the profitability of companies. It can also be influenced by how much is spent on inputs, be they imported or sourced domestically. When inputs are sourced domestically, then value added (which is reported in the indirect estimates) accrues to domestic industries or businesses that supply those inputs. If inputs are imported, then the value added accrues to businesses in the economy of origin and is not included in the value added calculation.

Additional Information on Value Added

Value added impacts vary from economy to economy and technology to technology based on production levels and a economy's ability to capture value added from that production. Ability to capture value added can vary based on earnings, domestic investors, and taxes less subsidies that industries pay or receive. Additionally, level of value added captured can depend on domestic sourcing of inputs. For example, if solar module producers buy cells that are produced in-economy, this supports more domestic value added than if they import cells.

Another way to frame value added results: purchasing power parity

Estimates of value added include earnings, profits, and returns on investment. Yet these dollar amounts can impact populations differently in terms of what they can purchase. This concept, known as purchasing power, can be affected by a number of conditions such as prevailing prices for goods and services and currency exchange rates. The World Bank and others have begun to study purchasing power parity by using conversion factors to show how much a specific basket of items costs in an economy. Typically, such parity is established relative to the United States (1.0 on the parity scale). Thus, the purchase power parity conversion factor for Mexico is 0.6, because a basket of goods that costs $10 in the United States would cost $6 in Mexico. If the same level of wages or returns on investment were paid to an individual in Mexico and to another individual in the United States, then the individual in Mexico would be able to purchase more because the basket of goods costs less.

Table A-1. Direct Value Added Divided by Production Revenue across Technologies and Economies

	LEDs	PV	Batteries	Wind	All
Brazil	–	–	–	35%	35%
Canada	–	41%	39%	44%	42%
China	15%	16%	15%	26%	20%
Germany	–	42%	42%	37%	38%
India	–	20%	–	21%	21%
Japan	37%	37%	36%	34%	37%
Malaysia	16%	16%	–	–	16%
Mexico	–	14%	–	37%	15%
Korea	23%	34%	23%	27%	26%
Taiwan	25%	25%	22%	–	25%
United Kingdom	–	–	45%	46%	46%
United States	65%	58%	63%	40%	48%
Total	26%	21%	33%	30%	25%

To see how clean energy manufacturers contribute to GDP of their economy, we divide direct value added by production revenue. This contrasts with value added levels, which are typically highest for economies with the highest levels of production. Normalized figures show how a commodity could contribute to an economy if production increased, although the figures do not show the feasibility of increasing production or market conditions (such as prices, strength of local currencies, taxes, or subsidies) that could drive increases or decreases in production.[62]

Table A-1 shows these calculations for all industries throughout the economy divided by revenue as well as value added from the production of all clean energy technologies in this report divided by revenue from all production.

Generally, manufacturers in three of the four technologies covered in this report produce higher percentages of value added from production than the average; batteries are the highest. PV is the exception. This trend varies from economy to economy, however, so it is not universally true. The factors that drive these differences between economies are discussed in the Clean Energy Manufacturing by Country section of this report.

Indirect value added, which incorporates the economic activity of businesses that supply goods and services to clean energy manufacturers, shows how clean energy manufacturers support additional value added throughout the economy. In some economies for some technologies, indirect value added exceeds direct value added. Table A-2 shows direct and indirect impacts combined as a percentage of revenue.

Adding indirect to direct changes the overall order of changes. Wind, rather than batteries, supports the highest value added per unit of revenue. Both LEDs and c-Si PV are below the 56% average across all technologies.

Tables A-3 – 10 are the total value added details for each of the technologies.

Table A-2. Direct and Indirect Value Added as a Percentage of Revenue

	LEDs	PV	Batteries	Wind	All
Brazil	–	0%	0%	82%	82%
Canada	–	63%	60%	67%	65%
China	40%	41%	54%	72%	53%
Germany	–	71%	70%	70%	70%
India	–	52%	0%	52%	52%
Japan	68%	68%	78%	82%	70%
Malaysia	27%	28%	0%	–	28%
Mexico	–	38%	0%	58%	38%
Korea	38%	51%	50%	47%	44%
Taiwan	41%	40%	47%	–	41%
United Kingdom	–	0%	67%	68%	67%
United States	82%	87%	87%	76%	80%
Total	47%	45%	68%	72%	55%

62. This should also not be interpreted as showing how investing in one technology might benefit an economy more than investing in another because it does not reflect why industries exist where they do.

Table A-3. Direct Value Added Retained (c-Si PV Components)

	Modules	Cells	Wafers	Polysilicon	Total – All Components
Brazil	–	–	–	–	–
Canada	41%	–	–	–	41%
China	15%	15%	15%	44%	16%
Germany	42%	42%	42%	41%	42%
India	20%	20%	–	–	20%
Japan	37%	37%	37%	42%	37%
Malaysia	16%	16%	16%	77%	16%
Mexico	14%	–	–	–	14%
South Korea	22%	22%	22%	58%	34%
Taiwan	25%	25%	25%	–	25%
United Kingdom	–	–	–	–	–
United States	65%	65%	65%	54%	58%
Total – All Economies in this Report	18%	19%	18%	48%	21%

Table A-4. Total (Direct and Indirect) Value Added Retained (c-Si PV Components)

	Modules	Cells	Wafers	Polysilicon	Total – All Components
Brazil	-	-	-	-	-
Canada	64%	-	-	-	63%
China	48%	48%	48%	85%	41%
Germany	73%	73%	73%	74%	71%
India	57%	57%	-	-	52%
Japan	82%	82%	82%	86%	68%
Malaysia	31%	31%	31%	87%	28%
Mexico	40%	-	-	-	38%
South Korea	56%	56%	56%	77%	51%
Taiwan	53%	53%	53%	-	40%
United Kingdom	-	-	-	-	-
United States	89%	89%	89%	90%	87%
Total – All Economies in this Report	50%	51%	51%	83%	45%

Source: OECD (2015) and NREL analysis

Table A-5. Direct Value Added Retained (Vehicle Li-ion Battery Components)

	Cells	Cathodes	Anodes	Separators	Electrolytes	Total – All Components
Brazil	–	–	–	–	–	–
Canada	–	39%	–	–	–	39%
China	15%	16%	16%	17%	18%	15%
Germany	42%	–	–	34%	–	42%
India	–	–	–	–	–	–
Japan	37%	35%	35%	27%	20%	36%
Malaysia	–	–	–	–	–	–
Mexico	–	–	–	–	–	–
South Korea	22%	26%	26%	25%	17%	23%
Taiwan	–	22%	–	20%	–	22%
United Kingdom	46%	–	–	–	35%	45%
United States	65%	41%	–	34%	35%	63%
Total – All Economies in this Report	36%	23%	22%	24%	20%	33%

Source: OECD (2015) and NREL analysis

Table A-6. Total (Direct and Indirect) Value Added Retained (Lithium Ion Battery Cells)

	Cells	Cathodes	Anodes	Separators	Electrolytes	Total – All Components
Brazil	–	–	–	–	–	–
Canada	–	61%	–	–	–	60%
China	48%	71%	71%	74%	72%	54%
Germany	73%	–	–	68%	–	70%
India	–	–	–	–	–	–
Japan	82%	84%	84%	81%	76%	78%
Malaysia	–	–	–	–	–	–
Mexico	–	–	–	–	–	–
South Korea	56%	60%	60%	57%	45%	50%
Taiwan	–	48%	–	48%	–	47%
United Kingdom	68%	–	–	–	65%	67%
United States	89%	78%	–	82%	85%	87%
Total – All Economies in this Report	72%	72%	74%	74%	70%	68%

Table A-7. Direct Value Added Retained (Wind Components)

	Nacelles	Blades	Towers	Steel	Generators	Total – All Components
Brazil	29%	41%	38%	26%	29%	35%
Canada	–	39%	45.9%	–	–	44%
China	21%	44%	19%	18%	16%	26%
Germany	37%	37%	40%	19%	38%	37%
India	26%	8%	25%	20%	19%	21%
Japan	35%	29%	–	30%	35%	34%
Malaysia	–	–	–	–	–	–
Mexico	–	–	37%	–	–	37%
South Korea	24%	–	28%	–	26%	27%
Taiwan	–	–	–	–	–	–
United Kingdom	–	–	46.0%	–	–	46%
United States	38%	48%	39%	16%	41%	40%
Total – All Economies in this Report	27%	41%	27%	18%	22%	30%

Source: OECD (2015) and NREL analysis

Table A-8. Total (Direct and Indirect) Value Added Retained (Wind Components)

	Nacelles	Blades	Towers	Steel	Generators	Total – All Components
Brazil	82%	90%	85%	82%	82%	82%
Canada	–	77%	69%	–	–	67%
China	77%	85%	72%	79%	71%	72%
Germany	71%	72%	73%	52%	72%	70%
India	56%	53%	57%	50%	53%	52%
Japan	85%	81%	–	77%	84%	82%
Malaysia	–	–	–	–	–	–
Mexico	–	–	71%	–	–	58%
South Korea	57%	–	59%	–	60%	47%
Taiwan	–	–	–	–	–	–
United Kingdom	–	–	70%	–	–	68%
United States	77%	86%	81%	69%	78%	76%
Total – All Economies in this Report	75%	82%	72%	74%	71%	72%

Source: OECD (2015) and NREL analysis

Table A-9. Direct Value Added Retained (LED Packages)

	Packages	Chips	Sapphire Substrate	Total – All Components
Brazil	–	–	–	–
Canada	–	–	–	–
China	15%	15%	20%	15%
Germany	–	–	–	–
India	–	–	–	–
Japan	37%	37%	45%	37%
Malaysia	16%	–	–	16%
Mexico	–	–	–	–
South Korea	22%	22%	29%	23%
Taiwan	25%	25%	23%	25%
United Kingdom	–	–	0%	–
United States	65%	65%	35%	65%
Total – All Economies in this Report	26%	25%	28%	26%

Source: OECD (2015) and NREL analysis

Table A-10. Total (Direct and Indirect) Value Added Retained (LED Packages)

	Packages	Chips	Sapphire Substrate	Total – All Components
Brazil	–	–	–	–
Canada	–	–	–	–
China	48%	48%	77%	40%
Germany	–	–	–	–
India	–	–	–	–
Japan	82%	82%	86%	68%
Malaysia	31%	–	–	27%
Mexico	–	–	–	–
South Korea	56%	56%	58%	38%
Taiwan	53%	53%	45%	41%
United Kingdom	–	–	–	–
United States	89%	89%	87%	82%
Total – All Economies in this Report	59%	58%	64%	47%

Source: OECD (2015) and NREL analysis

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