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Global value chain assessment based on retrospectively induced economic costs associated with technology application: A case study of photovoltaic power system in Japan

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ABSTRACT

Global warming is a worldwide problem that requires an international strategy to ensure compatibility of economic growth and overcoming climate change. Although global use of low-carbon technology is a solution, consideration of economic consequences is important to promote future technology development and use. Photovoltaic (PV) solar power system is a promising renewable technology that carries climate mitigation expectations. We conducted a value chain analysis to evaluate the economic effect of the manufacture and use of silicon PV solar power system worldwide. We quantitatively reviewed the flow of manufacturing and installation for cells, modules, and facilities (e.g., inverters) related to Japan, and estimated the retrospectively induced economic costs for Japan and other developed and developing countries. Material, equipment, labor, utility, transportation, and business operation costs were studied in detail at different manufacturing and installation stages. This unique evaluation methodology quantified economic costs from an international perspective. The retrospectively induced economic effect of 2014 PV solar power system sales in Japan (induced by cell module and system production by Japanese companies and increased domestic use) was 1.6 trillion Japanese yen worldwide, of which 63% was attributable to Japan, 10% to other developed countries, and 27% to developing countries. The economic effect in Japan in terms of equipment cost and installation stage was 37% and 71% of the total effect, which was particularly high. Further technical improvement, cost reduction, and improvement in inverter and manufacturing equipment reliability are important to capitalize Japan's strengths. Currently, Japan's involvement in the manufacturing of cells and modules is small. Therefore, both technical innovation and cost reduction are necessary. We present new methodology to obtain inputs into policy development for further research, development, and technology diffusion.

1. Introduction

Global warming must be mitigated as a common issue worldwide. Energy conservation and renewable energy technologies have multifaceted significance in reducing emissions. The importance of technology diffusion has been well-recognized by experts studying climate change. The United Nations Framework Convention on Climate Change continues efforts to stabilize atmospheric greenhouse gas concentration and adapt to impacts. Discussions on the framework beyond 2020 (when the Kyoto Protocol commitment period is over) have started. At the end of 2015, the 21st annual Conference of the Parties (COP21) adopted the Paris Agreement, which includes the following points in its decisions (MOE, 2015):

- Maintain the global average temperature increase after the Industrial Revolution within 2 °C and aim to limit the increase to 1.5 °C.
- All countries should submit or update reduction targets every five years and report their implementation in a common and flexible way for review.
- Utilization of market mechanisms that directly relate to the global division of decarbonizing opportunities.
- Importance of innovation.

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Nomenclature

C	Cost
C_{RIEC}	Retrospectively induced economic cost through the value chain
Q	Quantity of flow in the value chain (solar cell/module sales [W] between stages)
R	Ratio of retrospectively induced economic effect to each region
U	Unit cost (cost/W), cost divided by PV power output
CP	Suffix for Cell production stage
MP	Suffix for Module production stage
DS	Suffix for Distribution stage
IN	Suffix for Installation stage
mt	Suffix for material
eq	Suffix for equipment
lb	Suffix for labor
tr	Suffix for transportation and shipment
bs	Suffix for business profit and operation
$main$	Suffix for main equipment
Jp	Suffix for Japan
Os	Suffix for overseas
$Os\text{-}ic$	Suffix for overseas (other industrialized countries)
$Os\text{-}dc$	Suffix for overseas (developing countries)
r	Regions (Japan, other developed countries, or developing countries)
f	flow of stages/regions
i	Material
j	Equipment
JPY	Japanese Yen

The Japanese Intended Nationally Determined Contribution states that the target of greenhouse gas emissions by fiscal year (FY) 2030 should be 26.0% less than the FY 2013 level. The section on international contributions mentions that Japan's contribution to reducing greenhouse gas emissions through technology dissemination, including products and services, to developing countries would be quantitatively evaluated. To achieve Japan's reduction targets, a Joint Crediting Mechanism, one of the market mechanism schemes, will be utilized and expected to reduce emissions of 50–100 million tons of CO_2 in total by 2030. For other international contributions, it anticipates that "emission reduction potential in FY 2030 through the diffusion of leading technologies by Japanese industries' actions is estimated to be at least 1 billion t-CO_2." (UNFCCC, 2015) In addition, it also includes contributions "internationally toward, inter alia, human resource development and promotion of development and diffusion of technologies relating to emission reductions in developing countries." Together with the decision of the Paris Agreement, it can be said that the scheme or methodology to review, monitor, and verify the reduction of emissions and energy use is significant. Moreover, it is important to understand how to institutionally and financially promote the technology diffusion and transfer worldwide. The UN "2030 Agenda for Sustainable Development" adopted in September 2015 emphasized that the use of funds will become increasingly important and that various resources are required for sustainable development in developing countries, including official development assistance, domestic funds, and private funds.

Central to this is how we promote and use technology at a global level and cooperate for this purpose. We previously proposed an Integrated Contribution Approach (ICA) focused on promoting and transferring energy and environmental technologies as an effective way to reduce greenhouse gas (Tanaka et al., 2016). This may hold merits and opportunities for both developed and developing countries by quantifying the contribution to climate mitigation, promoting private investment incentives, and establishing a mechanism for business opportunities in the host country's economic development (Fig. 1). This is consistent with the concept confirmed in the Paris Agreement as well as the 2030 Agenda, as described above.

Although technology is central to solutions to worldwide problems such as climate change, the wide spread of technology requires a framework in which technology is spontaneously used in economic and development activities, rather than based on regulations and obligations. It is of the utmost importance to promote private investment incentives and to establish a mechanism to utilize various business opportunities for the host country's economic development. In considering such a framework, it is important to understand the regional economic impacts that accompany multilateral technical use, as discussed in this study. We evaluated the benefits of technology use to a target area on a global scale, with the aim of acquiring useful information to contribute to a framework to promote global technology development and use and identifying future possibilities for technology in the global market.

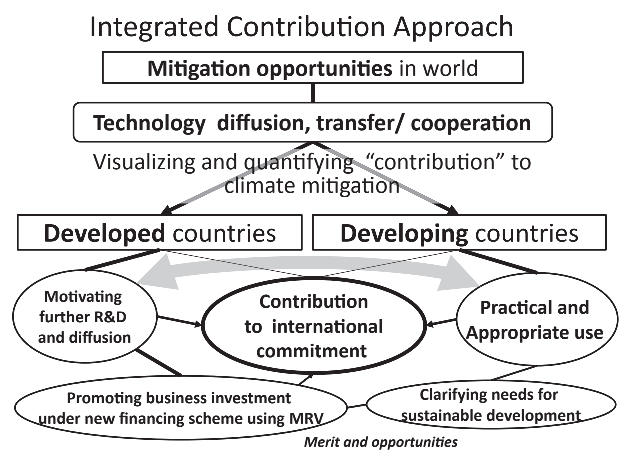

Fig. 1. Scope and objectives of the Integrated Contribution Approach.

To achieve this, we performed value chain analysis based on the cost structure to evaluate economic effects by manufacturing and use of a photovoltaic (PV) system technology. We focused on a photovoltaic (PV) solar power generation system that is expected to be a means of climate change mitigation. The PV system has been massively diffused at different levels of scale due to a sharp drop in cost in recent years, and it was expected that the annually introduced PV capacity would rapidly peak at 200 GW per year by 2050 (IEA, 2014). Companies in Japan and Germany had the largest share in PV market until 2000 in the developmental stage. During the diffusion stage, production companies were shifted to emerging countries such as China, Korea, and Taiwan. Because the PV major companies have been dramatically shifted, it is unclear which region the actual benefit belongs to. The objective of this research was to clarify the benefits of the area. Therefore, technologies that have become widespread on such a scale have been broadly procured, and a large influence on dissemination of cost reduction is