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An environmental life cycle comparison of single-crystalline and amorphous-silicon thin-film photovoltaic systems in Thailand

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ABSTRACT

Solar Photovoltaic (PV) technologies are gaining influence as a potential supplemental electricity source in Thailand. This study assesses the environmental and economic benefits of two types of photovoltaic technologies — single-crystalline and amorphous silicon thin-film systems. The advantages of building-integrated PV are also analyzed. The assessment considers embodied energy, CO_2 payback, and economic investment. Solar PV currently provides less than 1% of Thailand's electricity; however the government aims to generate 25% of its electricity from renewable sources by 2021. Different policy scenarios affecting life cycle performance, including manufacturing processes and geographic differences are explored. The results indicate that solar electricity can serve as a promising, untapped renewable energy source for Thailand to pursue in its efforts to wean away from imported natural gas and other fossil fuel energy sources. Amorphous silicon thin-film panels yield a greater net environmental benefit than single-crystalline technologies. Even if panels are made in a high electricity emissions country, like China, PV reduces GHG emissions. A sustainable grid-connected photovoltaic system would combine appropriate solar photovoltaic technologies. An economic comparison is included to contextualize the findings. Life Cycle Assessment (LCA) provides an invaluable tool for policymakers to evaluate such opportunities.

Introduction

Increased electricity demand in Thailand over the past decade at almost 770 MW per year provides the underlying motivation for Thailand to seek alternative domestic sources of electricity production. Currently to meet this growing demand, Thailand must import electricity from Laos, Myanmar, and China (EPPO, 2013). Additionally, Thailand seeks to alter its energy usage to reduce fossil fuel derived energy and increase production of renewable energy in an attempt to address climate change (Adhikari et al., 2008). In the 1970s, 90% of Thailand's energy was imported, but Thailand's resources now include recent discoveries of natural gas in the Gulf of Thailand and lignite in the Northern region. However, these recent discoveries of natural gas are insufficient compared to Thailand's increased electricity demand due to population and economic growth. In 2012, 66% of Thailand's electricity was generated from natural gas and 20% came from imported coal and lignite with approximately 40% of the natural gas being imported (EPPO, 2013). Furthermore, dependence on fossil fuel imports will encourage Thailand to harness its own energy resources. Thus, the Ministry of Energy set forth a plan to increase energy efficiency and security while simultaneously mitigating climate change. Without a dominant domestic energy resource, Thailand must consider several renewable energy supply options. One possible option explored in this analysis is rooftop solar electricity, requiring little to no additional land.

The Ministry of Energy established a “Very Small Power Producer” feed-in tariff subsidy for solar in 2006, which presently includes a 6.55 baht/kWh (~0.22 USD/kWh) “adder” to sell medium-scale (10–250 kW) rooftop solar electricity back to the grid in urban areas. This subsidy is comparatively large relative to other countries' solar feed-in tariffs, which is partially explained by not only a lack of inherent natural energy resources, but also the desire to promote solar technology. Single-crystalline and amorphous silicon thin-film solar panels are two pervasive types of solar photovoltaic technology available in Thailand to sell electricity back to the grid. Single-crystalline panels have a higher efficiency and amorphous-silicon thin-film panels are a lower cost PV technology. This study attempts to reconcile the environmental and economic differences between single-crystalline and thin-film photovoltaic technologies to assist policymakers in the formulation of GHG mitigation strategies.

Photovoltaics have rapidly gained a small share of Thailand's total electricity generation. In 2007, 0.14% of Thailand's electrical energy came from solar sources (Thailand's Energy Conservation and Renewable Energy Development Program 2008–2011, 2007). This share of

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grid-connected solar could surpass 1% in the next few years, as the current installed solar capacity already has exceeded previous policy targets of 95 MW by 2016 with the present share of all renewable electricity hovering around 5% of installed generation capacity According to the Department of Alternative Energy Development and Efficiency (DEDE) as of March 2013, solar reached a total generating capacity of 486.30 MW (Electricity Generating Authority of Thailand (EGAT), 2013). A quantitative assessment performed using Life Cycle Assessment methodology would aid the evaluation of policy options for proliferating solar electricity throughout Thailand as a GHG mitigation strategy and a domestic energy source.

Methodology

Goal and scope definition

The main objective of this study is to compare life-cycle GHG emissions, embodied energy, and economic investment of single-crystalline solar technologies with new amorphous-silicon thin-film solar panels. The secondary objective is to quantify the benefits of building-integrated photovoltaic modules (BIPV) compared to standard roof-mounted, grid-connected panels. BIPV modules replace conventional roof tiles and are fully integrated as part of the building's roof. The assumptions will include conventional roof tiles and the standard electricity grid mix of Thailand. The intended purpose is to develop an environmental basis for policymakers to pursue appropriate technologies when promoting the solar industry in Thailand. The study provides important information for Thailand that is applicable for similar sized countries that are developing solar PV electrification strategies.

Approach

This study follows Life Cycle Assessment methodology (LCA) based on ISO 14040/44 methodology (ISO, 2006a,b) and 2011 IEA Task 12 LCA Guideline (IEA, 2011) to compare the potential greenhouse gas mitigation strategies embedded in employing different solar technologies, while also discussing the potential shortcomings and policy incentives needed to enable widespread penetration of solar technology into Thailand. The LCA approach is used to compare GHG emissions from grid-connected single-crystalline and a-Si thin-film solar cells. Other environmental impacts are not included in this study.

Fig. 1 explains the scope. Building-integrated photovoltaic (BIPV) applications are also considered because of the high potential for GHG emissions reductions in Thailand due to conventional roof structures (Marsh, 2008; Yoon et al., 2011). BIPV applications include concrete roof production within the system boundaries because the function of the panel includes producing electricity and serving as a roof tile for the building (Raugei and Frankl, 2009). Different scenarios are considered for panels produced in Thailand and imported from China, Japan, and Germany. These countries are the major sources of solar panels in Thailand.

Functional unit

Based on insolation data and future potential efficiencies of amorphous-silicon thin film and single-crystalline solar panels at 7% and 15% respectively (IEA, 2011), the study will assume 30 years of electricity production equating to 2400 MWh of production in the year 2011. The functional unit, to which all calculations are normalized, is thus *2400 MWh of electricity generated*. To put the functional unit in perspective the installation would emulate a 60 kW rating for a commercial PV installation as detailed in Table 1.

Other assumptions

The typical estimate for the life of a solar panel is 30 years and will be assumed for both technologies (Hsu et al., 2012; Zhang and Dornfeld, 2010). Where single-crystalline panels require approximately 400 m^2 to provide 2400 MWh over a 30 year period, thin-film amorphous silicon panels would require 857 m^2. A de-rating factor for conversion from DC to AC electricity of 80% is assumed (Chaurey and Kandpal, 2009; Dalton et al., 2009; Kim et al., 2012). We consider that all PV generated will be used on-site and therefore we do not account for transmission losses. The insolation data is assumed to be an average for Bangkok, Thailand estimated using the PVSYST software tool (4.8 kWh/m^2/day) (Mermoud et al., 2009).

Secondary objective — Building integrated

In order to compare the technologies for the BIPV approach, the physical panel serves two roles: as electricity producing device and a roof tile. The conventional Thai roofs of large buildings that could support active solar panels are made of cement tiles. The lifetime of the cement tile is estimated to be 30 years based on analysis of tropical roofs (Halwatura and Jayasinghe, 2008). The major components of the life cycle are the production, use, and disposal phases, which are discussed further.

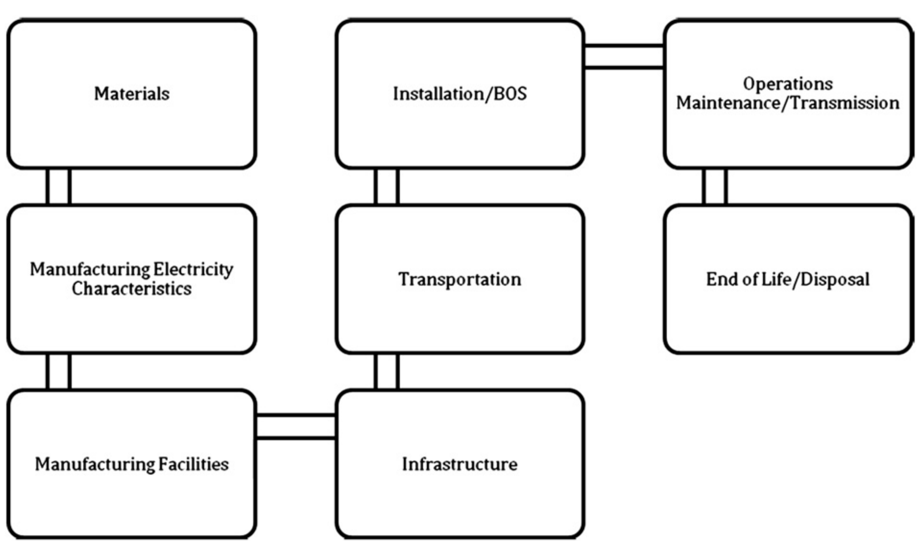

Fig. 1. A flow diagram of the overall LCA approach used to compare technologies.