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Applying analytic network process to evaluate the optimal recycling strategy in upstream of solar energy industry

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ABSTRACT

This research presents an evaluation model to evaluate the various recycling strategies to obtain the optimal recycling collection strategy in the upstream of the solar energy industry (SEI). The recycling process includes three major stages: (1) collection, (2) inspection, and (3) process. The proposed model combines the benefits, opportunities, costs and risks (BOCR) and balance scorecard (BSC) model. First, the evaluation model establishes a network with four perspectives, twenty indicators, and four strategies. Next, the analytic network process (ANP) is applied to the model to determine the relative weights of the evaluative criteria. Finally, the application of the multi-criteria decision making model will list the optimal strategies according to their rankings in the model. The results showed that the most important perspective is "Benefits;" the most crucial criterion of the 20 criteria is "economic and financial benefits;" and the best strategy is "In-house" (IH). Thus, when a business in the upstream of the SEI applies the model, the business will reveal that its optimal strategy for recycling and waste disposal shall be In-house treatment at the collection stage.

These research results can provide both academic supports to the decision-makers in the upstream of the SEI and valuable guidance for evaluating their recycling programs to obtain optimal strategies in their actual administration of the recycling practices.

1. Introduction

In recent years, the solar energy industry (SEI) is one of the most booming and cleanest resource industries in the world. The main advantage of using solar energy is its ability to access clean and environmentally friendly electricity without consuming fossil fuels [1,2]. Solar energy does not deplete natural resources, does not, cause CO_2 or other gaseous emissions to diffuse into the air, and does not generates liquid or solid waste products [2]. Concerning sustainable development, the advantages of using solar energy, whether directly or indirectly derived, include following [2–5]:

- No emissions of greenhouse (mainly CO_2, NO_x) or toxic gasses (SO_2, particulates);
- Reclamation of degraded land;
- Reduction of transmission lines from electricity grids;
- Improvement of quality of water resources;
- Increase of regional/national energy independence;
- Diversification and security of energy supply;
- Acceleration of rural electrification in developing countries.

Consequently, literatures approved that SEI is vital to the trend of global environmental concerns. Many countries are actively developing, enhancing and installing Photovoltaic (PV) electricity [2] (see Table 1); scholars also forecast that the quantity of PV installations will generate 70,000 Megawatts (MW) in 2020 and 140,000 MW in 2030.

The SEI has a highly complicated business structure. The supply chain of the SEI requires processing certain materials and includes at least the following five steps: (1) raw silicon material, (2) wafers/ingots, (3) PV cells, (4) PV modules and (5) PV system. The upstream is step 1 and step 2; midstream is step 3 and downstream is step 4 and step 5 as shown in Fig. 1 [1,6–8]. Research papers published by the European Photovoltaic Industry Association (EPIA) [9] showed the trend that the numbers of companies in the PV supply chain are decreasing moving from downstream to upstream (Table 2). At the same time, more customers in the PV supply chain are moving from upstream to downstream. According to Table 1, the installations of the PV systems reached 70,000 MW in 2020 and 140,000 MW in 2030. Pavlović et al. [10] showed that about 20,000 m^2 of space is required to install a fixed 1 MW PV solar plant. Thus, the installation of PV plants will occupy very

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Table 1
Development and installation of solar photovoltaic electricity in various countries.

Year	USA (MW)	Europe (MW)	Japan (MW)	Worldwide (MW)
2000	140	150	250	1000
2010	3000	3000	5000	14,000
2020	15,000	15,000	30,000	70,000
2030	25,000	30,000	72,000	140,000

Source: [2].

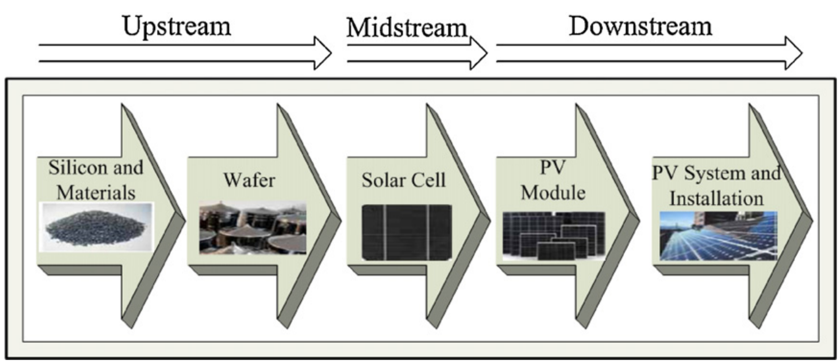

Fig. 1. Supply chain of the SEI [1,6–8].

Table 2
Number of companies' world-wide in the PV value chain in 2009.

	Silicon	Wafer/ingots	Cells	Modules/system
Number of companies:	75	208	239	988
Production capacity:	130,000 Tonnes	15,000 MW	18,000 MW	19,000 MW
Effective production:	90,000 Tonnes	10,000 MW	9000 MW	7000 MW

Source: [9].

large parcels of land. Additionally, Solar PV modules contain hazardous materials such as cadmium, tellurium, lead and selenium. Cadmium compounds are, for example, currently regulated in many countries because of their toxicity to fish and wildlife and because they can pass to humans through the food chain [11]. Cadmium has also been associated with numerous human illnesses particularly lung, kidney and bone damage and once absorbed in the body; cadmium can remain for decades [12]. These chemicals materials or waste are very dangerous in human future life and global environment. That may become a big environmental problem when

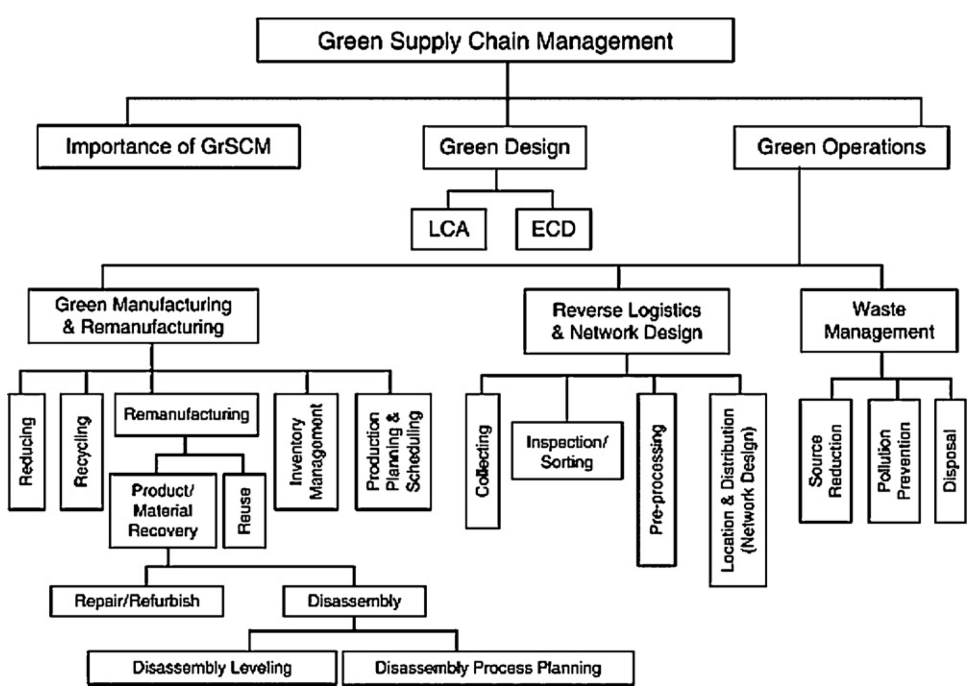

Fig. 2. Classification based on GSCM [17].