

Peer Reviewed Journal Publications by UNC Undergraduate Students at the Thai KMUTT field site as supported by the UNC Institute for the Environment, UNC Study Abroad and faculty at King Mongkut's University of Technology at Thonburi (KMUTT)

1. Comparison of Electric, Compressed Natural Gas, and Diesel Buses in Thailand: A Life Cycle Perspective

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Abstract: The public transportation system in Bangkok, Thailand relies on environmentally costly diesel buses that contribute daily to Bangkok's air quality problem. Two potential improvements to this highly polluting public transportation system are the implementation of electric or compressed natural gas buses. This paper analyzes the life-cycle environmental impacts using the ReCiPe life cycle impact assessment method (in Global warming, kg CO₂ eq, Stratospheric ozone depletion, kg CFC-11 eq, etc.), technical feasibility of implementation, and financial cost of implementing each bus type in Bangkok by calculating these metrics for a single bus and then scaling them to a fleet of that bus type. The entire life cycle of the buses as well as electric bus charging infrastructure is considered. It was found that shifting from diesel to electric or compressed natural gas buses would present a 54-55% or 37-41% decrease in overall damage to human and ecosystem health, an 88% or 80% decrease in resource depletion, and a 48% or 60% decrease in lifetime costs. If the entire diesel bus fleet in Bangkok of approximately 14,127 buses is converted to electric or compressed natural gas buses, the reduction of fine particle (PM_{2.5}) transportation emissions would be approximately 21% and 18%. Of compressed natural gas and electric buses, compressed natural gas buses are the less expensive alternative, while electric buses cause less damage to the ecosystem, human health, and resource depletion. Because the extent of environmental impacts of electric buses depends on the source of electricity production, electric buses also have the potential to reduce environmental impacts with cleaner electricity production as it becomes available.

2. Life cycle assessment of a floating photovoltaic system and feasibility for application in Thailand

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Abstract: The performance of floating photovoltaics (FPV) was assessed by this study, a technology with rising popularity in the sustainable energy sector, by comparing its economic and environmental benefits to various types of photovoltaic technologies by utilizing Life Cycle Assessment (LCA) and Cost-Benefit Analysis. The largest impacts were shown from this LCA of a 150 MW FPV plant with a 30-year lifespan, which resulted from the roughly 73 kg of greenhouse gases and 110 m³s of water per MWh generated. Additionally, 21 reservoirs were considered in Thailand to house new FPV plants. Projected power generation scenarios varied between 0.64 GW and 13.28 GW when reservoir coverage percentages ranging from 1% to 20% were used. The Levelized Cost of Energy for several different photovoltaic systems yielded 0.24 USD per kWh for the FPV system, while the ground based polycrystalline and thin film systems were 0.43 USD and 0.54 USD per kWh, respectively. The payback period for FPV was 7.5 years, while for the polycrystalline and thin film it was 7.8 and 16.3 years. This combined with other factors made for a high return on investment for the FPV system. This study recommends a 10% coverage of 21 reservoirs throughout Thailand, allowing for potentially 6.52 GW of installed capacity, which would substantially help the country to reach their 2036 goal of having 30% of the energy mix from renewable sources.

3. An Assessment of Mortality Attributable to Ambient PM_{2.5} in Bangkok, Thailand

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Abstract: Multiple studies indicate that PM_{2.5} is the most deleterious air pollutant for which there are ambient air quality standards. Daily concentrations of PM_{2.5} in Bangkok, Thailand continuously exceed the World Health Organization (WHO) and the Thai

National Ambient Air Quality Standards (NAAQSs). Bangkok has only recently begun to measure concentrations of PM_{2.5}. In order to overcome this lack of data, daily PM_{2.5}/PM₁₀ ratios were generated over the period 2012-2018 to interpolate missing values. Concentration-response coefficients (β values) for PM_{2.5} versus non-accidental, cardiopulmonary, and lung cancer mortalities were estimated to be 0.001192, 0.002284, 0.003134, respectively. These values are comparable to those reported in the literature for a Chinese population, but considerably lower than those reported in literature from the United States. These findings strongly suggest that specific regional β values should be used to accurately quantify the number of premature deaths attributable to PM_{2.5} in Asian populations. Health burden analysis using the Environmental Benefits Mapping and Analysis Program (BenMAP) showed that PM_{2.5} concentration in Bangkok contributes to 3,754 non-accidental, 1,317 cardiopulmonary, and 370 lung cancer mortalities annually. Further analysis showed that the attainment of PM_{2.5} levels to the NAAQSs and WHO guideline would reduce premature mortality in Bangkok by 25% and 71%, respectively.

Keywords: daily PM_{2.5}/PM₁₀ ratios, concentration-response coefficients, health burden, health benefit, Bangkok

4. Third Generations of Photovoltaic Panels: a Life Cycle Assessment

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Abstract: This study analyzed the impacts from multi-crystalline silicon (m-Si), organic thin-film (OPV), and perovskite thin-film (PSC) panels over each products' lifetime using a cradle-to-grave system model. The rate of panel installation each year was modeled to account for efficiency, functional lifetime, and degradation. Landfill and recycling scenarios were used to compare end-of-life impacts and the overall environmental impacts were determined using life cycle impact assessment at the midpoint and endpoint levels. Impact calculations revealed that the production and use of m-Si panels resulted in the worst impacts for all categories. OPV panels produced drastically lower impacts comparatively, with PSC designs falling at mid-range. Recycling lowered the impacts for all module types and showed the largest decrease in the impacts of m-Si panels. Although moderately sensitive to the energy production mix, the results can be applied to other regions for the comparison between panel types.

5. A history of the rehabilitation of mangroves and an assessment of their diversity and structure using Landsat annual composites (1987–2019) and transect plot inventories

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Abstract: Recently, there has been renewed interest in the ecosystem services of mangroves such as carbon sequestration or coastal protection, and consequently, the development of tools providing an effective and automatic monitoring of the dynamics of mangrove land coverage including rehabilitated or naturally regenerated forest stand is increasingly demanded. Satellite-based time series analysis in coastal areas can be limited by atmospheric contaminations, such as haze, and clouds and their shadows. Here, we present an “automatic regrowth monitoring algorithm” (ARMA) using the Google Earth Engine (GEE), based on Landsat interannual median composites from 1987 to 2019 with 30 m spatial resolution. The species and structural diversity were assessed using transect plot inventories. The Landsat-based normalized difference infrared index (NDII) and information obtained from plot inventories were used to assess the characteristics of the natural and rehabilitated mangrove forests. The ARMA identified the starting year of the rehabilitation project using the satellite data, the required stability period after the rehabilitation, and the stand age in the year 2019. The information obtained from the field survey data were linked to the results obtained using the ARMA. After 28 years, the rehabilitated mangroves at the study site consist of monocultures of Rhizophoraceae, while the undisturbed and naturally regenerated mangroves had greater species diversity. Nevertheless, the rehabilitated mangroves were found to reach the height of the adjacent natural mangroves. The period required to reach a stable NDII value (similar to natural stands) after rehabilitation ranged from 7 to 13 years. The careful assessment of the NDII upward trend was crucial for the performance of the ARMA. The application presented here shows, however, that the system can be used to evaluate both small- and large-scale rehabilitation projects. The results of this study provide valuable baseline information for the site assessed and for its comparison with other rehabilitated mangroves in Thailand. Due to the technical potential, we are convinced that the ARMA system is suited to investigate changes in mangrove coverage dynamics, in general, including gain (as presented here), but also mangrove losses, due to disturbances such as degradation or forest diebacks.

6. An integrated assessment of particulate respirators used as personal protection from ambient air pollution in Bangkok, Thailand

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Abstract: The recent increase of fine particulate matter in Bangkok, Thailand has become a widespread public health concern. Wearing a particulate respirator is one method to reduce particulate inhalation and therefore mitigate the adverse health effects of ambient air pollution. This study provides an integrated assessment of seven particulate respirator models based on three criteria: effectivity, cost, and environmental impact. The overall effectivity of each model is evaluated by assessing the product's features associated with facial fit. The cost criterion reflects current market prices for bulk and individual orders. Thirdly, an environmental impact score is determined for the product life cycle of each respirator using life cycle assessment. The study assesses each respirator as it would be manufactured, distributed, used, and disposed of in Bangkok, Thailand. The integrated assessment results in twelve distinct consumer frameworks, reliant on variations of the three criteria, to provide guidance for policy makers and independent consumers in the selection of particulate respirators to optimally suit their needs. Ultimately, the data suggest that a buyer's ideal respirator choice for short-term use is a disposable particulate respirator with a head strap. For long-term use, the study recommends a low-cost reusable respirator with an exhalation valve and replaceable filters. The average effectivity of reusable respirators is found to be greater than that of disposable respirators, due to their higher average number of available sizes. Reusable respirators are associated with consistently lower environmental impacts. The short-term cost of disposable respirators is much less than those of reusable models, however prices do converge over time.

7. A multi-scenario life cycle impact comparison of solar energy storage systems in Thailand.

Rachael Tevis^{a,b}, Natalie Schuster^{a,b}, Felix Evans^{a,b}, Robert Himmler^{b,c}, Shabbir H. Gheewala^{b,c,d,*} *Energy & Buildings* 190, 172–182, 2019.

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Abstract: This study provides a life cycle assessment (LCA) of a sustainably designed office building to be built in Thailand. The building has a gross floor area of 6300 m² and a lifetime of

50 years. An analysis of four different energy supply scenarios was performed to evaluate methods for reducing grid electricity demand with the goal of optimizing renewable energy usage and minimizing environmental impacts. The scenarios included: (1) the conventional, grid-dependent building, followed by (2) the addition of a rooftop photovoltaic (PV) system, (3) a PV system with lithium-ion battery storage, and (4) a PV system with an ice storage system. Scenarios 3 and 4 were included in this study as 16% of the electricity from PV was overproduced during the weekends when the building was unoccupied. The results show that scenarios 2, 3, and 4 reduced operational grid consumption by 33%, 37.8%, and 37.9% but increased metal depletion potential by 23.9%, 34.4%, and 29.0%, respectively. Ice storage led to the greatest reduction in lifetime environmental impacts. Efficient production and utilization of renewable energy in buildings is vital to reducing nonrenewable fuel dependence; however, it is necessary to minimize metal depletion in the implementation of such technologies.

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8. The Environmental and Economic Impacts of Photovoltaic Waste Management in Thailand

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Abstract: Renewable energy technology is being adopted into energy plans worldwide to reduce the mounting CO₂ emissions of traditional energy sources. Currently in Thailand, there are approximately 15 million solar panels (2600 MW) which will need to be disposed of in the coming years. The average lifespan of a crystalline silicon panel is between 20 and 30 years, and responsible treatment of these end-of-life panels is necessary to minimize environmental burdens. Thailand's current plan is to landfill these panels. This study hopes to shed light on the environmental and economic paybacks that could materialize from recycling solar panels. It has been hypothesized that recycling solar panels could result in less environmental burdens than landfilling, but at an added monetary cost. Using LCA methodology and the EcoInvent database, this paper compares the environmental impacts of landfilling end-of-life crystalline silicon panels with those of two different recycling methods. By recycling silicon-based solar panels, valuable metals within the panels can be recovered instead of lost to the landfill. Recycling PV panels is less environmentally burdensome than landfilling when credits are applied to the recycling methods for the avoided production of materials that are recovered from the panels. Using the discounted cash flow method, this paper also compares the three waste management plans financially, as costs will inevitably influence how PV waste is managed in Thailand in the years to come. Neither of the recycling facilities were found to be economically profitable, however the cost to recycle could be as little as \$0.03 per kg.

9. An Environmental Life Cycle Assessment of rooftop solar in Bangkok, Thailand

John Eskew ^a, Meredith Ratledge ^a, Mike Wallace ^aShabbir H. Gheewala ^{b,d,e}, Pattana Rakkwamsuk ^c *Renewable Energy*, 123, 781-792, 2018.

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Abstract: As solar photovoltaic (PV) technologies gain momentum as an energy source both in Thailand and the world, more attention needs to be brought to their associated environmental impacts. The purpose of this study is to quantify the environmental burdens created by a planned rooftop PV solar installation on a university campus in Bangkok, Thailand, and to model the potential of rooftop solar to meet the country's renewable energy goals. Impacts are evaluated with Life Cycle Assessment methodology for the seven-component solar installation and recommendations made for upstream purchasing decisions according to different scenarios. Results indicate the main contribution to impacts occurs in manufacturing by stage and from PV modules by component. Impacts generated by the mounting structure and inverters are also significant, and together these three components constitute over 90% of environmental burdens. An equivalence of 0.079kg CO₂-eq./kWh of electricity is produced over the lifetime of the system. Energy Payback Time is calculated as 2.5 years, and the Economic Payback Period is 7.4 years. The system is estimated to avoid 1.00E+06kg CO₂-eq. over its lifetime. Installation of similar rooftop PV systems on 50% of university and government buildings in Bangkok could result in a net reduction of 4.80E+09kg CO₂-eq. Domestic production of components and recycling of materials is identified as a best-case scenario, with alleviations across all impact categories. Economic analysis suggests on-site electricity consumption paired with a net-metering policy scheme is the best way to incentivize PV solar energy installations.

Keywords: Photovoltaic, Life Cycle Assessment, Rooftop Solar, Renewable Energy, Thailand

10. Cycle Assessment: A multi-scenario case study of a low-energy industrial building in Thailand

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Abstract: This paper is a Life Cycle Assessment (LCA) of a Thai, low-energy industrial building currently under construction with a gross floor area of 14,938 m² and 20-year lifetime. Few comprehensive LCAs have been performed on non-residential low energy buildings, especially on industrial buildings. This study addresses this gap and attempts to establish a precedent that industrial buildings in emerging nations can follow to moderate energy demand and environmental externalities. A 5% air-conditioned area, LED-lighting and passive ventilation architecture minimized operation phase burdens; consequently, the manufacturing phase yielded largest impacts in primary energy demand (71%), global warming potential (60%), and every other assessed category. This is mostly attributed to steel and concrete production. Four scenarios—a base case, recycling case, photovoltaic system scenario, and combined recycling/photovoltaic scenario—were simulated to evaluate strategies for further energy reduction. Analysis indicated that significant life cycle energy savings can be achieved through recycling (29%) and a rooftop PV system (64%). Combining these enhancements results in a building with zero or sub-zero energy demand over its life cycle, compensating for all manufactured material embodied energies. Buildings that are already low-energy can further reduce environmental impacts through inclusion of the aforementioned approaches in infrastructure and implementation.

Key Words: Life cycle assessment • Industrial building • Recycling • Embodied energy • Low energy • Rooftop PV

11. Water Quality Degradation and Management Strategies for Swine and Rice Farming Wastewater in the Tha Chin River,

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Abstract: Water quality in the Tha Chin River regularly exceeds biological oxygen demand (BOD) standards of Thailand's Enhancement and Conservation of National Environmental Quality Act. This study quantified the BOD loading from rice cultivation and swine farming to the Tha Chin River using effluent data and procedures from the Pollution Control Department (PCD), geospatial land-use maps from the Land Development Department, and water quality data from the Ministry of Natural Resources and the Environment. It was determined that the BOD loading was 12 tons/day from swine farming in 2015 and 52 tons/day, on average, from rice farming between 2002 and 2011. Technology-specific, community-scale wastewater management strategies were recommended for both industries: feasibility studies revealed 66 potential sites for

constructed wetland implementation and 7 subdistricts suitable for biogas network pipelines. It was determined that if these projects are implemented in conjunction, the BOD would be reduced by 6% (0.3 mg/L) in the entire river or 11% (0.5 mg/L) at the three water quality monitoring stations proximate to swine farms. These reductions would have a substantial effect on the water quality of the Tha Chin River, and governmental agencies such as the PCD should strongly consider subsidization and implementation of these projects.

12. Greenhouse gas assessment of palm oil mill biorefinery in Thailand from a life cycle

Gabrielle Beaudry¹, Caroline Macklin¹, Elizabeth Roknich¹, Laney Sears¹, Margaret Wiener¹, Shabbir H. Gheewala^{2,3}, *Biomass Conversion and Biorefinery* DOI: 10.1007/s13399-016-0233-7, 1-16, 2017.

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Abstract: The purpose of this study is to provide a comprehensive assessment of oil palm biomass waste utilization, with the goal of providing palm oil mill owners the best options for biomass applications in order to limit carbon emissions and optimize economic potential. As the third largest producer of palm oil in the world, Thailand is very entrenched in the industry and thus is an ideal country to implement waste utilization strategies. The biomass byproducts result from the processing of fresh fruit bunches (FFB) from the oil palm plant in order to extract the main commodity, crude palm oil (CPO). This paper assesses six major biomass byproducts that result from the processing of the oil palm plants: empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fiber, oil palm fronds, oil palm trunks, and palm oil mill effluent (POME). The associated net greenhouse gas emissions were calculated for each biomass' potential utilization pathway. The results of the study found that 4 of the 6 biomass waste products have alternative utilization options that resulted in net negative carbon emissions. Regarding the utilization options that are recommended, EFB shows net emissions of -0.14 t CO₂ equivalent, -5.33 for shells, -17.68 for fiber, and -0.594 for trunks. In addition, the assessment of the added value for each product guides decision making to ensure economic viability. This analysis is unique in that it encompasses various utilization pathways for each of the major oil palm waste products in one comprehensive study. By comparing the results of these pathways, an optimal use for every waste product is recommended to decrease the overall climate change impact of the mill.

Keywords

LCAPalm oil biorefineryEmpty fruit bunchesPalm kernel shellsOil palm trunkPalm oil mill effluent

Electronic supplementary material

The online version of this article (doi:[10.1007/s13399-016-0233-7](https://doi.org/10.1007/s13399-016-0233-7)) contains supplementary material, which is available to authorized users.

13. Comparative Life Cycle Assessment of a Thai Island's Diesel/PV/Wind Hybrid Microgrid

John Burrows^a, Shabbir H. Gheewala^{b,c}, Eric Scheier^a, Cameron Smith^a, Jessica Smith^a, Amberli Young^a, Tiffany Young^a, *Renewable Energy*, 80, 85–100, 2015.

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Abstract: Hybrid microgrid systems are an emerging response to the perceived need for rural electrification due to their purported environmental benefits. This study uses the method of Life Cycle Assessment (LCA) to compare the environmental burdens of the diesel/PV/wind hybrid microgrid designed for installation on the island of Koh Jig, Thailand with the electrification alternatives of grid extension and home diesel generators. The results show that the designed microgrid system had the lowest impact potentials in global warming and abiotic resource depletion potential, but not in acidification and human toxicity potential. As the performance of the microgrid differed from the design, the actual performance scenario is presented for consideration and shown to have little impact. Assumption analyses show that diesel combustion contributes significantly to the impacts of the system and that an increase in the renewable energy fraction of the system produces mixed results with regard to the four impact categories considered. The variation in final results across the chosen impact categories indicates that weighting is necessary to determine the environmental sustainability of the Koh Jig microgrid, and therefore it cannot simply be assumed environmentally sustainable. This reflects the inherent dilemma in determining any form of sustainability.

14. Transportation Fuels from Algae: Addressing Bangkok's Petroleum Needs

Ty Fenton, Lauren Riedle Wilton Burns, Emily Love, and Mary Katherine McKenzies, , Richard Kamens, Gheewala Shabbir* *Journal of Sustainable Energy and the Environment*, 5, 53-60, 2014.

Abstract: The purpose of this study is to assess the practicality of algal biofuel production and consumption in Bangkok, Thailand based on the environmental impacts of and ability to offset the petroleum equivalents. A life cycle assessment was conducted to determine the environmental impacts of algal biofuels - biodiesel, ethanol, and compressed biomethane - replacing low-sulfur diesel, standard gasoline, and compressed natural gas (CNG), respectively. Three scenarios with two algae strains were compared for the production of biofuels using net energy ratio (NER) and vehicle kilometers traveled (VKT). For *B. braunii*, the biodiesel and compressed biomethane producing scenario had the highest VKT of 1,220,000 and an NER of 1.26 using a 1,000 km functional unit. For the "generic" strain, biodiesel and compressed biomethane produced the highest VKT of 1,200,000 with a NER of 1.25. For *B. braunii* and generic strains, the production of only compressed biomethane showed NERs of 1.45 and 1.50 respectively, but VKTs of 936,000 and 976,000. Environmental impacts from algal biofuels are higher than petroleum fuels in all categories considered. Available land area would yield enough algal biofuels to replace

<1% of petroleum fuel usage. The production of transportation fuels from algae is not recommended for Bangkok.

Keywords: algae, biofuels, *B. braunii*, life cycle assessment, petroleum, renewable

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15. Life Cycle Assessment and Feasibility Study of Small Wind Power in Thailand

Keith A. Glassbrook^a, Adam H. Carr^a, Mark L. Drosnes^a, T. Reade Oakley^a, Richard M. Kamens^{a,b}, Shabbir H. Gheewala^{c,d} *Energy for Sustainable Development* 22 66–73, 2014.

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Abstract: The Thai government's renewable energy plan to help increase energy independence and reduce emissions includes a component from wind. Due to Thailand's wind regime, small wind turbines that can operate in low wind speeds are needed to meet this goal. This study assesses the environmental implications and economic feasibility of small wind turbines. Using a functional unit of producing 50 kWh per month for 20 years, a Life Cycle Assessment was conducted comparing the global warming potential (GWP100), embodied energy, energy payback period (EPP) and levelized cost of electricity (LCOE) of four small wind turbines (≤ 20 kW), a diesel generator, and the Thai grid. The turbines had a lower overall GWP100 compared to the diesel generator and Thai grid in areas with reasonable wind resources; the same was true for embodied energy when compared to the diesel generator. Interestingly, in most available wind speed categories in Thailand the LCOE for wind turbines was lower than for the diesel generator. However, neither could compare to the selling price of the Thai grid, except in the areas with the highest average wind speeds (7.0 -9.4 m/s). Because of the increased cost relative to the Thai grid, implementation of wind turbines in Thailand was not found to be economically feasible without government incentive.

Keywords

Wind energy, life cycle assessment, Thailand, Small wind turbines

16. Comparative Life Cycle Assessment Of Tropical Island Municipal Solid Waste Strategies

Tait Chandler, Amanda Drake, Evan Brown, Huston Julian, Nicole, Simonsen, Christiana Ade, Komslip Wangyao, Richard Kamens, Shabbir H. Gheewala, *Journal of Sustainable Energy and the Environment*, 5, 75-84, 2014.

Abstract: An increase in tourism, and subsequently of waste production on Thai islands, has required some islands to reevaluate their traditional incineration-based waste management schemes in the past ten years. Koh Phuket and Koh Samui in the southern part of Thailand are two Thai islands that have pursued contrasting paths in the attempt to deal with this increasing amount of waste since 2011. The purpose of this study is to determine which overall strategy is both more environmentally suitable and financially feasible. These islands serve as a guide for the comparison of two waste management scenarios: mass incineration versus the use of materials recovery technology with separation, dry anaerobic digestion of organic waste, plastic pyrolysis, wood plastic composite (WPC) production, and refuse-derived fuel (RDF) production with incineration and energy capture. A life cycle assessment and a basic cost analysis are utilized to determine the best path for future waste management planning on tropical islands. It was found that mass-burn incineration yielded higher environmental impacts in 6 of the 8 impact categories analyzed and a higher capital cost. These included xxx, yyy, etc. However, the materials recovery technology specified in the study produced a higher impact on Pphotochemical-oxidant formation, and particulate matter formation, as well as higher operation and maintenance costs. Despite these costs, the sale of usable co-products in this scenario creates a higher profit, making this scenario more recommendable.

17. An Environmental Life cycle Comparison of Single-crystalline and Amorphous-silicon Thin-film Photovoltaic Systems in Thailand

Noah Kittner ^a, Shabbir H. Gheewala ^{b,c}, Richard M. Kamens ^{a,d} *Energy for Sustainable Development*, 17, 605–614, 2013.

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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 enefits of two types of photovoltaic technologies — singlecrystalline and amorphous silicon thin-film systems. The advantages of building-integrated PV are also analyzed. The assessment considers embodied energy, CO2 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.

18. The Life Cycle Assessment of a solar-assisted absorption chilling system in Bangkok, Thailand

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Abstract: Life cycle assessment (LCA) methodology following ISO 14044:2006 standard is utilized to analyze the environmental impacts of implementing a solar/electric hybrid cooling system in a stadium of 15,000 seating capacity. Four impact categories are investigated: 100 year global warming potential (GWP), acidification potential, eutrophication potential, and abiotic resource depletion (ARD) potential. The life cycle emissions of the solar-assisted AC system are compared to that of a conventional, electricity consuming vapor compression (VC) chilling system. The use-phase electricity consumption of the VC and the life time cooling production of the solar-assisted AC are simulated. The results yield reduced AC system net life cycle impacts for GWP, acidification, eutrophication and ARD potentials by factors of 25.8, 40.1, 33.6, and 37.7%, respectively, when compared with those of the VC system. It is found that use-phase impact savings due to the cooling production of the solar AC outweigh the higher non-use phase (raw material extraction, refining, unit manufacturing, transportation, and disposal) impacts of the solar-assisted AC system, and thus the system is found to be environmentally advantageous. The results are applicable to similar cooling systems and building systems within Southeast Asia.

Keywords: life cycle assessment, absorption chiller, solar-assisted absorption chilling, vapor compression chiller, life cycle emissions, Thailand

19. Life Cycle Considerations for Monocrystalline Photovoltaics in Thailand

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Abstract: Electricity from solar photovoltaics (PV) is gaining attention in Thailand, since the Ministry of Energy set forth targets to produce 25% of its electricity from renewable sources by 2021. Monocrystalline PV (mc-Si), the most energy-conversion efficient type photovoltaic module, is widespread as a solar technology in Thailand. Understanding the potential greenhouse gas emission reductions is increasingly important for evaluating renewable energies. This paper

evaluates different parameters from a life cycle perspective that affect climate change mitigation. The primary objectives are to quantify the different life cycle effects on resulting greenhouse gas (GHG) emissions for electricity produced by mc-Si panels for grid-connected systems in Thailand. The study considers the effects of energy efficiency measures, location of production, installation, building-integrated options, and climatic effects. A life cycle assessment suggested that monocrystalline panels can generate electricity with approximately ten times fewer GHG emissions than Thailand's average electricity mix. The inclusion of building-integrated applications reduces the life cycle impact even further by a factor of 3. With potential for significant GHG emission reductions, mc-Si PV grid-connected electricity production can serve as a possible climate change mitigation strategy for Thailand. This paper outlines the ways that different parameters can alter life cycle GHG emission results.

Keywords: life cycle thinking, monocrystalline PV, climate change mitigation, Thailand.

20. The Net Cost of Biofuels in Thailand—An economic analysis

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Energy Policy 39, 834–843, 2011.

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Abstract: Biofuels are expected to represent a growing portion of liquid fuel consumption in Thailand due to environmental and social considerations in conjunction with policy goals supporting their domestic production and consumption. This paper reviews the economic costs associated with biofuel policy implementation in Thailand in the short term target year of 2011. Internal (production) and external (environmental, social, etc.) costs and benefits are evaluated, and, where possible, monetized. Domestic production of biofuel is calculated to be 9.5 billion THB (317 million USD) more expensive than importing the equivalent amount of petroleum. The environmental benefits from GHG savings as well as losses due to increased ground level ozone formation and government expenditure to support the biofuel industry yield a total “net cost” of 8.6 billion THB or 121 THB (4.04 USD) per capita for the year 2011. This result is contextualized with the (non-monetized) consideration that although biofuels are somewhat more expensive in the short term, their domestic production allows virtually all of the money to stay within the Thai economy as opposed to being sent abroad. This fact, coupled with significant uncertainty in future petroleum prices, could strongly influence the direction of Thai policy with respect to biofuels. 2010 Elsevier Ltd. All rights reserved.

21. Effects of 10% Biofuel Substitution on Ground Level Ozone Formation in Bangkok, Thailand

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Abstract: The Thai Government's search for alternatives to imported petroleum led to the consideration of mandating 10% biofuel blends (biodiesel and gasohol) by 2012. Concerns over the effects of biofuel combustion on ground level ozone formation in relation to their conventional counterparts need addressing. Ozone formation in Bangkok is explored using a trajectory box model. The model is compared against O₃, NO, and NO₂ time concentration data from air monitoring stations operated by the Thai Pollution Control Department. Four high ozone days in 2006 were selected for modeling. Both the traditional trajectory approach and a citywide average approach were used. The model performs well with both approaches but slightly better with the citywide average. Highly uncertain and missing data are derived within realistic bounds using a genetic algorithm optimization. It was found that 10% biofuel substitution will lead to as much as a 16 ppb peak O₃ increase on these four days compared to a 48 ppb increase due to the predicted vehicle fleet size increase between 2006 and 2012. The approach also suggests that when detailed meteorological data is not available to run three dimensional airshed models, and if the air is stagnant or predominately remains over an urban area during the day, that a simple low cost trajectory analysis of O₃ formation may be applicable.