Life Cycle Analysis of HWS Gates Road Solar Farm

A Focus on Carbon Emissions

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What is Life Cycle Assessment?

- Purpose: quantify the material an energy inputs needed to create a product and the environmental impact of those inputs
- Process

Determine the intended application and bounds of the LCA

Collect and compile data on the inputs of the product being analyzed within the defined scope

Determine the environmental impacts of those inputs

("Life Cycle Assessment", 2007)

Open LCA

- OpenLCA: open source software that allows its users to upload existing LCA databases and compile that data into product systems using flows and processes

Flows 

- The physical materials used to create a certain product
- Can be raw material/energy, a pollutant, or a combination of previous flows

Processes 

- The collection of physical materials that are used to create a new flow
- Each flow within the bounds of an LCA that is not raw material or emissions should have an accompanying process

Product Systems 

- All of the flows involved in the making of a final product and their connection to one another

(Ciroth et al., 2020)

Open LCA cont.

Preexsting Flows

Processes

Inputs

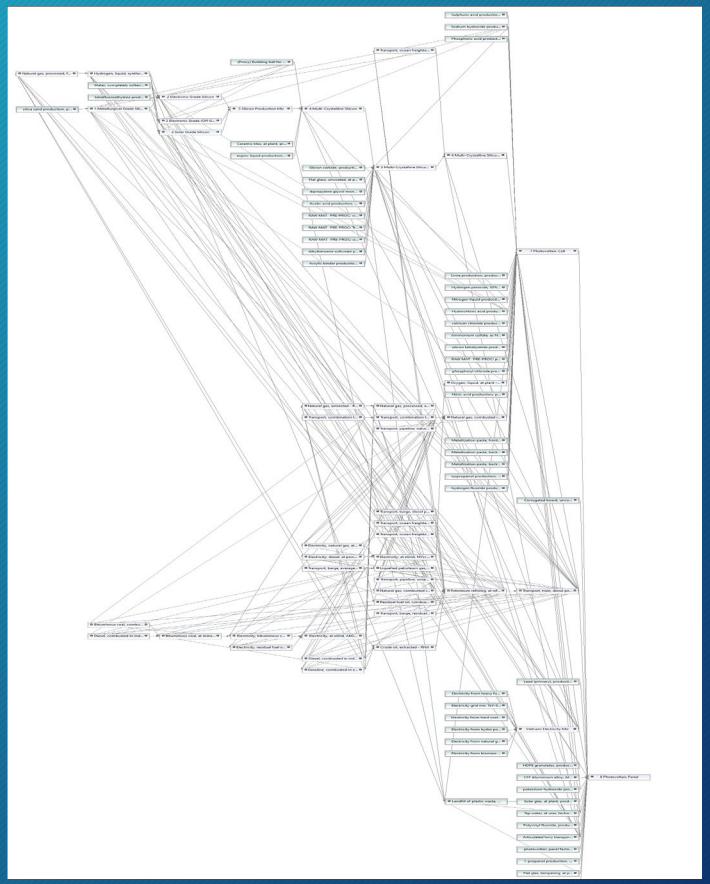
Flow	Category	Amount	Unit	Costs/Re...	Uncertai...	Avoided ...	Provider
Heat, at cogen with ignitio...	Technosphere Flows/...	46.50000	MJ		none		
Hydrochloric acid	Organic chemicals/n...	0.38200	kg		none		P Hydr...
Hydrogen, liquid, synthesis...	31-33: Manufacturin...	0.02390	kg		none		P Hydr...
Silicone plant/RER/I U	Systems/Other syste...	2.84000E-12	Item(s)		none		P (Prox...
Sodium hydroxide	Organic chemicals/n...	0.12400	kg		none		P Sodiu...
tetrafluoroethylene	Organic chemicals/n...	0.00017	kg		none		P tetraf...
Transport	Materials production...	2.15000	tkm		none		P Artic...
Transport, train, diesel pow...	48-49: Transportation...	0.02480	t*km		none		P Trans...
Water, completely softene...	EF Miscellaneous	18.50000	kg		none		P Wate...

Outputs

Flow	Category	Amount	Unit	Costs/Re...	Uncertai...	Avoided ...	Provider
2 Electronic Grade (Off G...	**Jinko Panel Product...**	**1.00000**	**kg**		**none**		

New Flow

Product System



LCIA Methods

- LCIA Methods are the coefficients and calculations necessary to complete an impact assessment

Impact factors

Impact category: Global warming (GWP100a)

Flow	Category	Flow property	Factor	Unit
Butane, 1,1,1,3,3-pentafluo...	Emission to air/unspecified	Mass	804.0	kg CO2 eq/kg
Butane, perfluoro-	Emission to air/high populati...	Mass	9200.0	kg CO2 eq/kg
Butane, perfluoro-	Emission to air/low populatio...	Mass	9200.0	kg CO2 eq/kg
Butane, perfluoro-	Emission to air/low populatio...	Mass	9200.0	kg CO2 eq/kg
Butane, perfluoro-	Emission to air/lower stratosp...	Mass	9200.0	kg CO2 eq/kg
Butane, perfluoro-	Emission to air/unspecified	Mass	9200.0	kg CO2 eq/kg
Butane, perfluorocyclo-, PF...	Emission to air/high populati...	Mass	9540.0	kg CO2 eq/kg
Butane, perfluorocyclo-, PF...	Emission to air/low populatio...	Mass	9540.0	kg CO2 eq/kg
Butane, perfluorocyclo-, PF...	Emission to air/low populatio...	Mass	9540.0	kg CO2 eq/kg
Butane, perfluorocyclo-, PF...	Emission to air/lower stratosp...	Mass	9540.0	kg CO2 eq/kg
Butane, perfluorocyclo-, PF...	Emission to air/unspecified	Mass	9540.0	kg CO2 eq/kg
Butanol, 2,2,3,3,4,4,4-hepta...	Emission to air/unspecified	Mass	34.0	kg CO2 eq/kg
Butanol, 2,2,3,3,4,4,4-hepta...	Emission to air/unspecified	Mass	16.0	kg CO2 eq/kg
Butanol, 2,2,3,4,4,4-hexaflu...	Emission to air/unspecified	Mass	17.0	kg CO2 eq/kg
Carbon dioxide	Emission to air/high populati...	Mass	1.0	kg CO2 eq/kg
Carbon dioxide	Emission to air/low populatio...	Mass	1.0	kg CO2 eq/kg
Carbon dioxide	Emission to air/low populatio...	Mass	1.0	kg CO2 eq/kg
Carbon dioxide	Emission to air/lower stratosp...	Mass	1.0	kg CO2 eq/kg
Carbon dioxide	Emission to air/unspecified	Mass	1.0	kg CO2 eq/kg
carbon dioxide (fossil)	Emissions to air/Emissions to ...	Mass	1.0	kg CO2 eq/kg
carbon dioxide (fossil)	Emissions to air/Emissions to ...	Mass	1.0	kg CO2 eq/kg

Flows

Coefficients

Units

- This LCA uses the CML 2001 Baseline method, developed by the Institute for Environmental Sciences at Leiden University in the Netherlands

In this example CML-baseline uses the Global Warming Potential of CO2 over 100 years as the unit to assess the impact of all GHGs. Each GHG is multiplied by a specific coefficient to reflect its potential to pollute.

Databases

- LCA databases are comprised of various flows and processes that can be connected in anyway the user desires. This project uses two databases
  1. Product Environmental Footprints: a database created as part of the European Commission's Single Market for Green Products initiative.
  2. USLCI: a database created by the National Renewable Energy Laboratory in the US

HWS Gates Road Solar Farm

- 8600 multi-crystalline solar panels
  - Each panel is ~1.94 m^2
  - ~3,800 produced in Vietnam
  - ~4,800 produced in Poland
- Each panel is produced by the Jinko Solar Company, a Chinese panel manufacturer
  - Eagle 72, 320-340 watt model
- The farm also contains 37 50/60kw solar inverters
  - Each is produced by Chint Power Systems, a North American energy company
  - All inverters are made in China

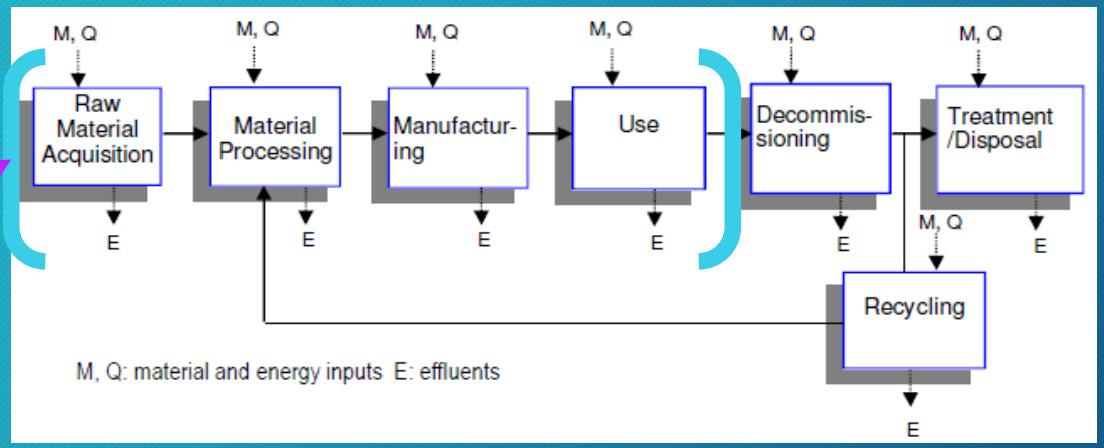
Goal

- To provide an academic audience with a descriptive analysis of the carbon emissions resulting from the Gates Road Solar farm's construction
  - The solar farm is not meant to be changed, instead the purpose of this LCA is to educate about the unseen environmental problems associated with a solar farm's production

Scope and Data

- A focus on GHGs
  - Only impact assessments on emissions with a global warming potential will be provided
- Cradle to use
  - The disposal of the solar installation is not accounted for

The analysis will focus on this portion of the product's life cycle



(Frischknecht et al., 2015)

Inventory Analysis: Photovoltaic Panel

- Data on panel production is from the IEA's 2015 report on the life cycle inventories and assessments of photovoltaic systems
- Data on Polish and Vietnamese electricity mixes is from iea.org

Polish Electricity Mix

Energy Source	Percent
Coal	73.7%
Wind	9.2%
Natural Gas	9.2%
Biomass	4.3%
Hydropower	1.6%
Oil	1.1%
Other	0.9%

Vietnamese Electricity Mix

Energy Source	Percent
Hydropower	44.8%
Coal	34.1%
Natural Gas	20.7%
Oil	0.4%

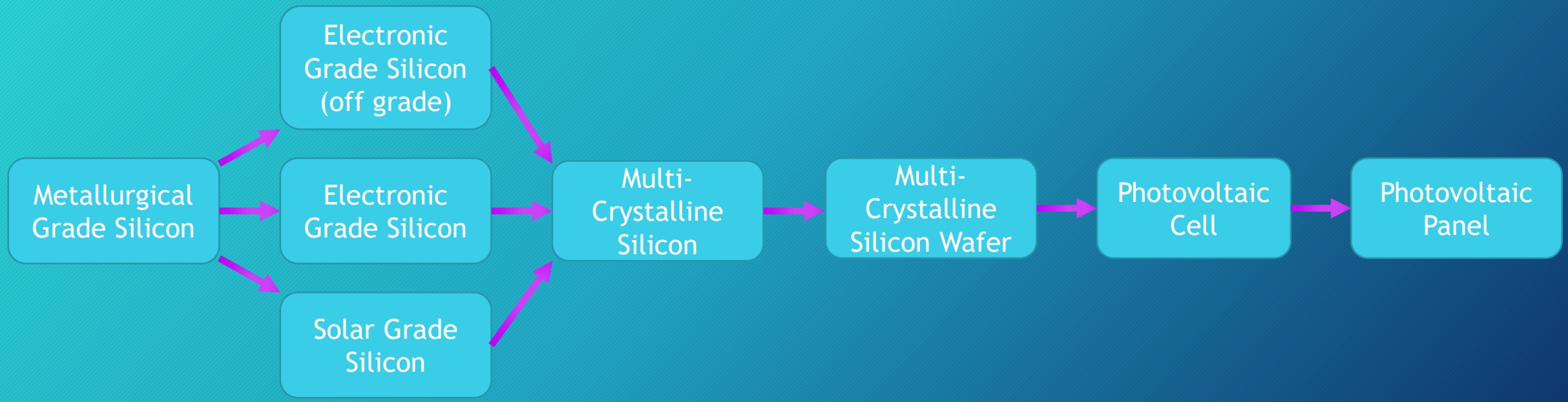
Inventory Analysis: Photovoltaic Panel

- Notable missing/cutoff flows
  - Charcoal
  - Graphite
  - Helium
  - Brass
  - Low-Alloyed Steel
  - Copper
  - Polyethylene Terepthalate
  - Silicone Product
  - Diesel, burned in building machine
  - Ethylvinylacetate
  - Isopropanol
  - Wire Drawing
  - Any disposal of physical waste (e.g. slag, hazardous waste, solid waste, etc.)

*The processes involved in the production of these flows were unavailable in both the Environmental Footprints and NREL databases

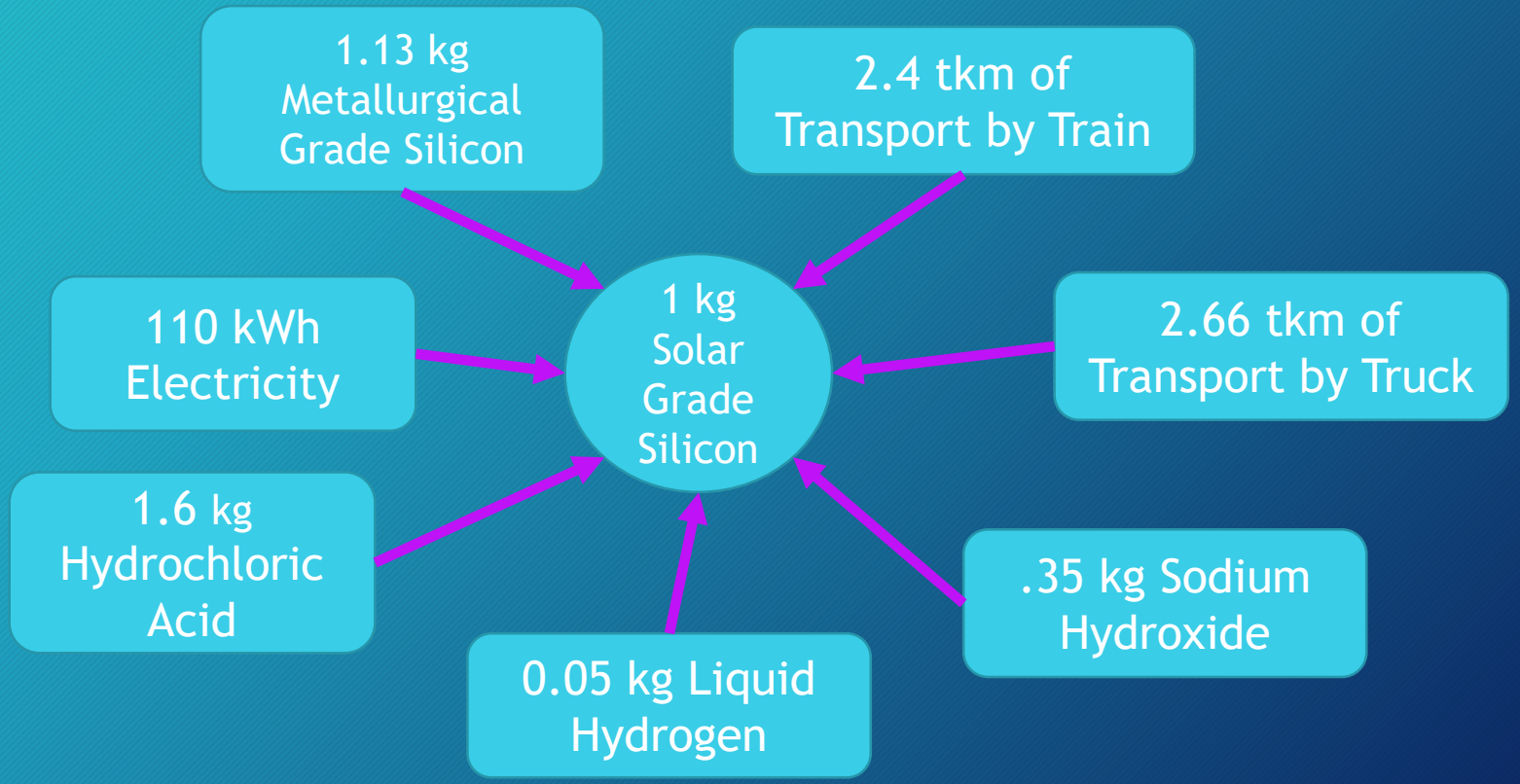
Inventory Analysis: Photovoltaic Panel

Main Production Process



Inventory Analysis: Photovoltaic Panel

Solar Grade Silicon Example

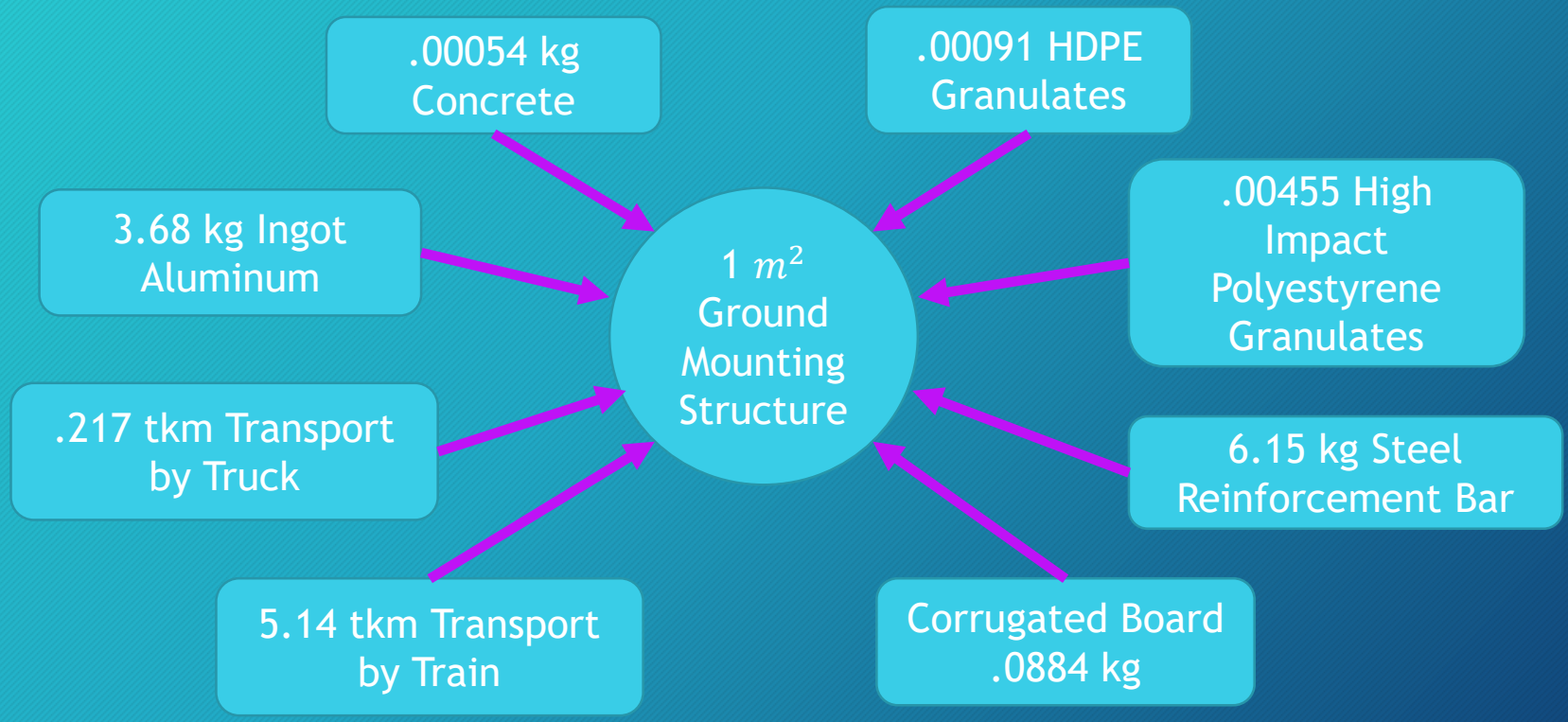


Inventory Analysis: Ground Mounting Structure

- Data for ground mounting structures also comes from the IEA's 2015 report
- Notable missing/cutoff flows
  - Reinforcing Steel
  - Chromium Steel
  - Wire Drawing Process
  - Zinc Coating

Inventory Analysis: Ground Mounting Structure

Ground Mounting Structure Production Process

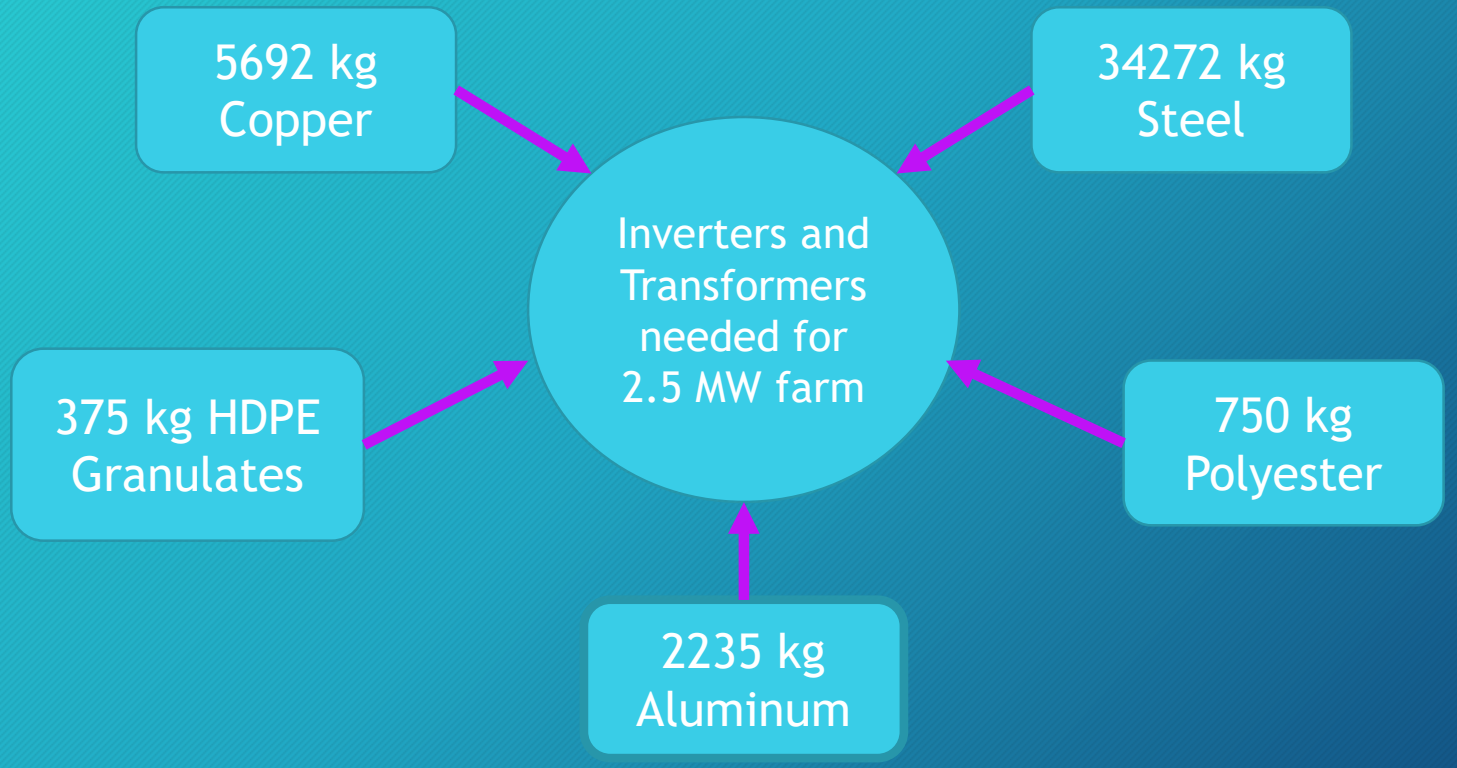


Inventory Analysis: Solar Inverters and Transformers

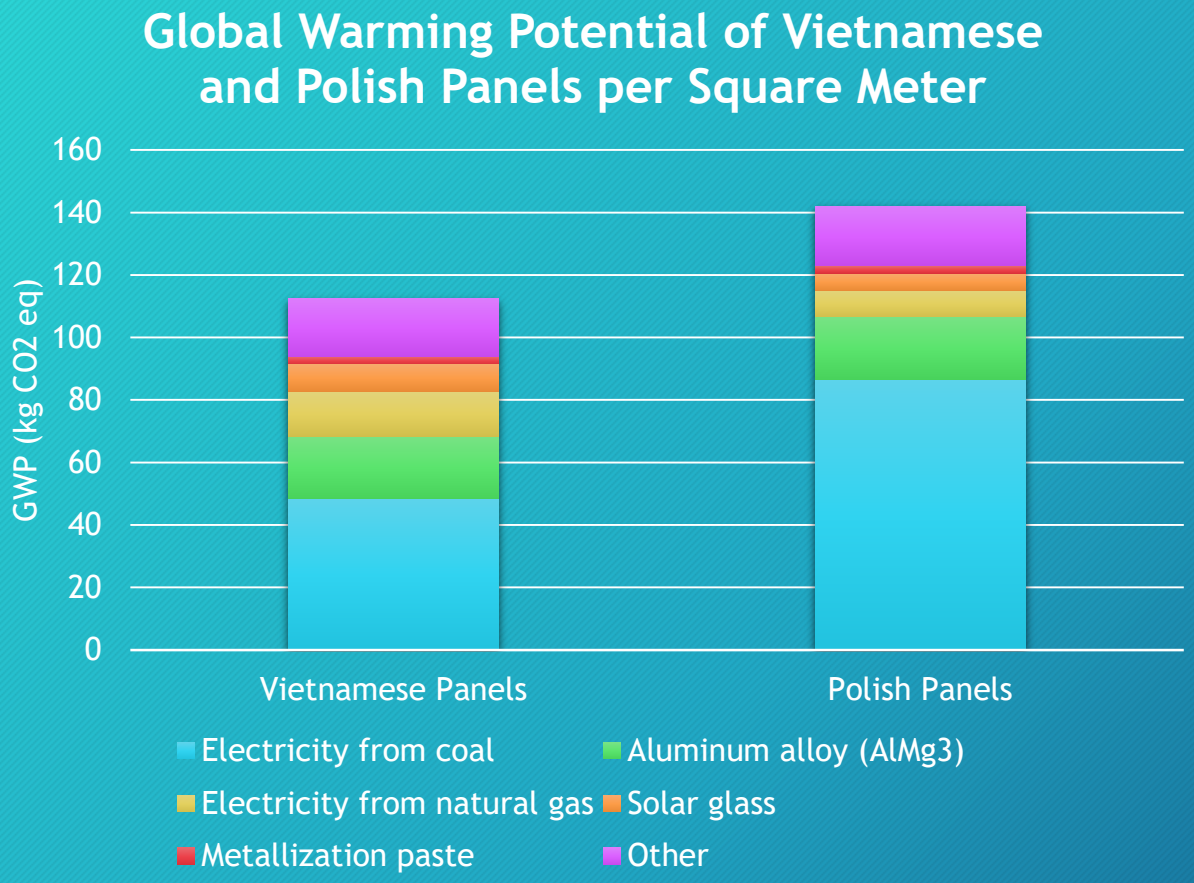
- Data is also from IEA's 2015 report on photovoltaic systems
- Due to scarce availability of life cycle data on inverters and transformers, the inventory data on this portion of the farm is derived from the 4.6 MW Springerville plant in Tucson, AZ
  - The data is scaled down to 2.5 MW to reflect the size of the Gates Road farm

Inventory Analysis: Solar Inverters and Transformers

Gates Road Inverter and Transformer System



Impact Assessment: Photovoltaic Panel



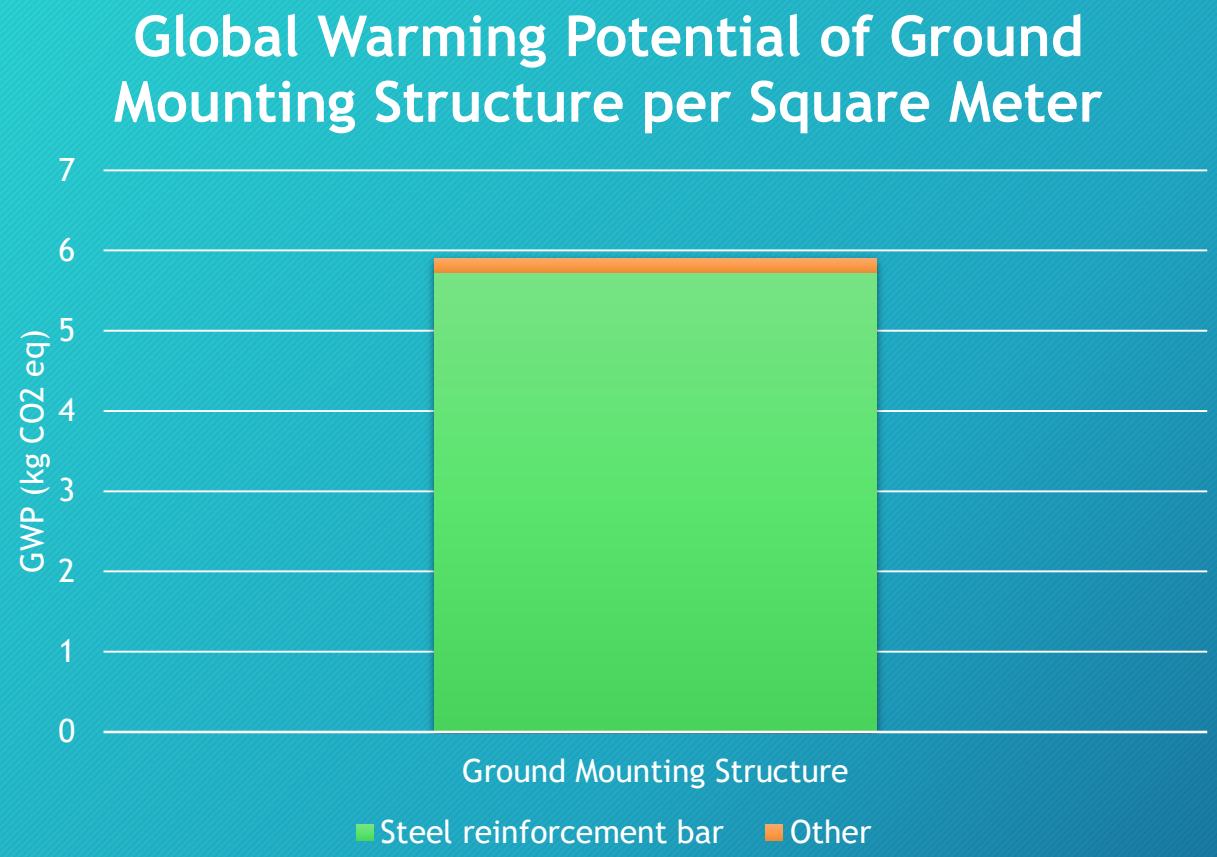
Vietnamese Panel Total GWP

112.5 kg CO2 eq/m^2 panel

Polish Panel Total GWP

142.0 kg CO2 eq/m^2 panel

Impact Analysis: Ground Mounting Structure

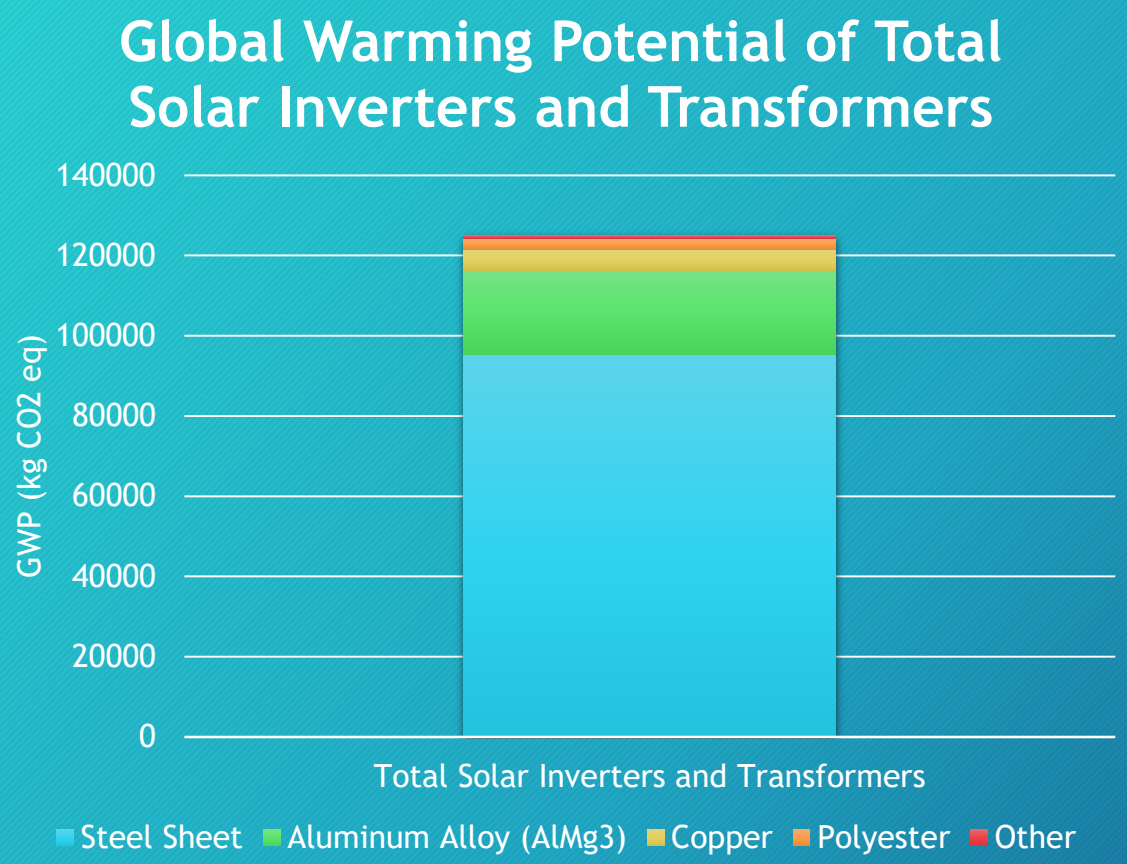


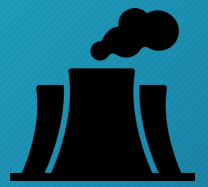
Ground Mounting Structure

5.9 kg CO2 eq/m^2 *

* The unit for ground mounting structures is derived from the amount of material needed to support one square meter of pv panel

Impact Analysis: Solar Inverters and Transformers





Total Inverters and Transformers

125,022.4 kg CO2 eq

Impact Analysis: Total Farm

Panel Specifications

Panel area=1.94 m^2 Total Panel Area=16684 m^2 (Vietnames Panels=7372 m^2 and Polish Panels=9312 m^2)

Expected Lifetime=25 years Expected Lifetime Generation=69.95GWh

Vietnamese Panels

(112.5 kg CO2 eq/m^2 + 5.9 kg CO2 eq/m^2) x 7,372 m^2=

872,845 kg CO2 eq

Polish Panels

(142.0 kg CO2 eq/m^2 + 5.9 kg CO2 eq/m^2) x 9312 m^2=

1,377,245 kg CO2 eq

Total Farm Global Warming Potential

872,845 kg CO2 eq + 1,377,245 kg CO2 eq + 125,022 kg CO2 eq = **2,375,112 kg CO2 eq**

Vietnamese Panels

Polish Panels

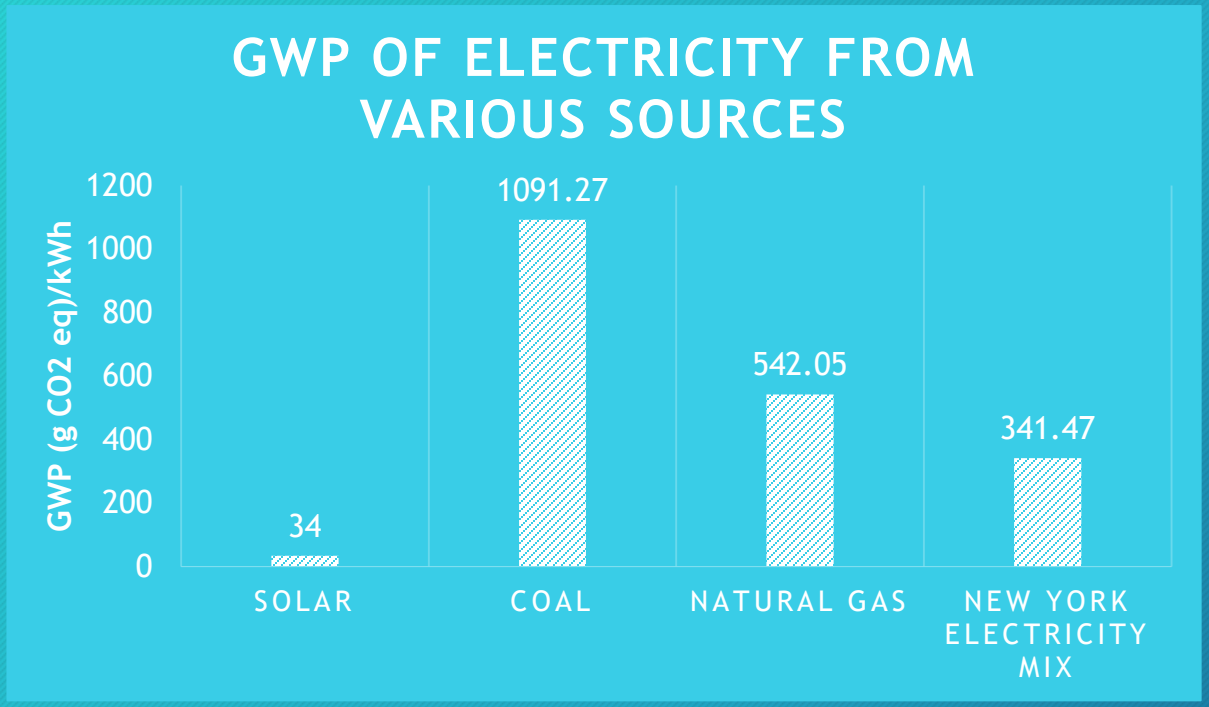
Inverters and Transformers

Impact Analysis: Per kWh

Panel Specifications

Expected Lifetime=25 years

Expected Lifetime Generation=69.95GWh



Grams CO2 eq/kWh

2,735,112,000 kg CO2 eq/69,950,000 kWh=

~34 g CO2 eq/kWh

- NREL estimates ~40 g CO2/kWh emitted using solar panels
- After 25 years the colleges will have avoided emitting 22,599,045 kg CO2 eq, equivalent to the emissions of…
  - 5,425 cars in one year
  - 7 days of electricity generation at the Greenidge Power-Plant

("Greenhouse Gas Emissions", n.d.)

("Environmental Assessment", 2004)

Limitations

- Flows and processes from the NREL and EF databases may not represent Jinko's exact panel production process
  - Ex: electricity mixes may not match what is used at Jinko's factories in Poland and Vietnam
- Missing flows and processes means the impact analysis is slightly undervalued
- The values used for panel lifespan and lifetime electricity generation are estimations, and may be inaccurate
- The issue with cutoffs
  - This analysis assumes that all materials used in the production process would not have been made otherwise
  - There is no way to know that the production of these materials would have been avoided if the panels were not created

Sources

Ciroth, A, et al. “OpenLCA 1.10 Comprehensive User Manual.” Feb. 2020.

“Environmental Assessment: Greenidge Multi-Pollutant Control Project.” Aug. 2004.

Frischknecht, Rolf, et al. International Energy Agency, Upton, New York, 2015, *Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems*.

“Greenhouse Gas Emissions from a Typical Passenger Vehicle.” *EPA*, Environmental Protection Agency, 10 May 2018, www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle#:~:text=typical passenger vehicle?-,A typical passenger vehicle emits about 4.6 metric tons of,8,887 grams of CO2.

“Life Cycle Assessment: A Product Oriented Method for Sustainability Analysis.” 2007.