# Exploring Secondary Markets to Improve Circularity: A comparative case study of photovoltaics and hard-disk drives

Liam Watts, Julien Walzberg, Alberta Carpenter, Garvin Heath

July 20th, 2021

Background –
Problem statement

- **Problem:** Currently 1.5 million photovoltaic (PV) solar panels and 50 million hard-disk drives (HDDs) reach product end-of-life (EOL) annually (IRENA-IEA 2016, iNEMI 2017).

- **A solution?** The circular economy (CE) can utilize EOL products to reduce amount of landfilled material
  - In 2040 projected PV waste = 2-4 million tonnes
  - CE could reduce PV waste through recycling and reuse, lowering raw material demand and GHG emissions

- Techno-economic solutions are necessary but not sufficient to improve the circularity of the PV life cycle (Salim et al., 2019)
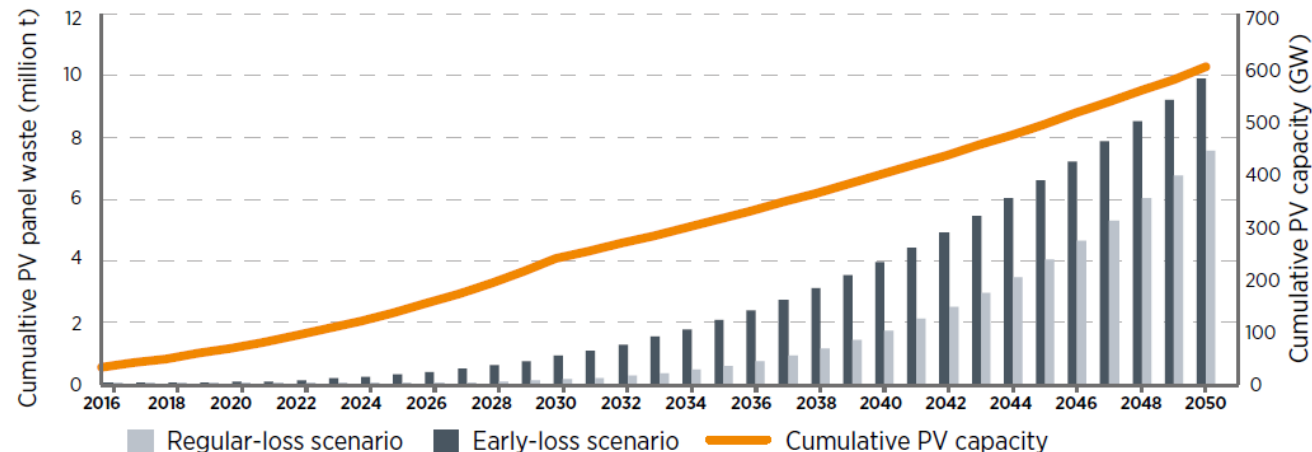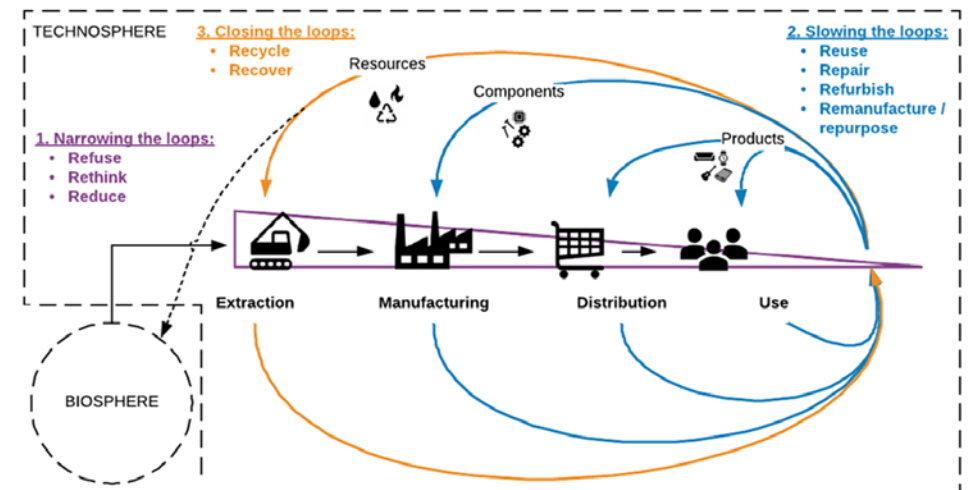

Projected cumulative capacity and projected EOL PV modules (IRENA-IEA 2016)
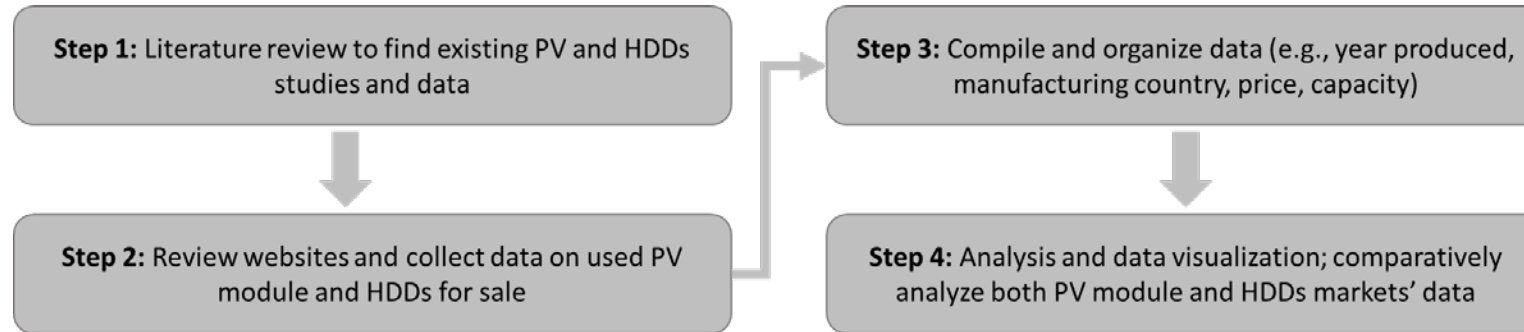
PV and HDD Secondary Markets – Objectives

1. Contribute to the CE research by collecting data on primary and secondary PV and HDD markets

2. Identify the shortcomings of the secondhand PV market through comparison with the secondary HDD market to improve available knowledge about secondhand modules

   - Existing PV secondhand market information on module pricing is conflicting:
     - Tao and colleagues state **50%** of new module price (Tao et al., 2020)
     - Unpublished IEA PVPS Task 12 estimates **40%**
     - IRENA-IEA 2016 report estimates **70%** (IRENA-IEA 2016)

Diagram of a circular economy adapted (Institut EDDEC, 2018 Circular Economy model)

TECHNOSPHERE

3. Closing the loops:
- Recycle
- Recover

2. Slowing the loops:
- Reuse
- Repair
- Refurbish
- Remanufacture / repurpose

1. Narrowing the loops:
- Refuse
- Rethink
- Reduce

Resources   Components   Products

Extraction   Manufacturing   Distribution   Use

BIOSPHERE

PV and HDD Methods –
Steps and Process

Overview:

Step 1: Literature review to find existing PV and HDDs studies and data

Step 2: Review websites and collect data on used PV module and HDDs for sale

Step 3: Compile and organize data (e.g., year produced, manufacturing country, price, capacity)

Step 4: Analysis and data visualization; comparatively analyze both PV module and HDDs markets' data

Collection Process:

- Various available methods for collecting market data: literature, market reports, interviews, or web-scraping
    - **literature review** to identify any similar studies
    - **market reports** for collecting any historic data related to new or secondhand PV and HDD data
    - **interviews** for identifying the types of data available on certain PV and HDD websites
    - **web-scraping** for collecting any current PV and HDD available data

PV and HDD Collection –
Steps 1 and 2

Details:

-<u>New</u> PV market prices (price per watt) collected from Wood Mackenzie 2019 report
-<u>New</u> HDD market prices (price per terabyte) collected from Coughlin 2020

-<u>Secondhand</u> PV market prices were scraped from 2 websites and manually collected from 1 (20 websites were assessed for viability)
-<u>Secondhand</u> HDD market prices were scraped from diskprices.com

Sample of Python bs4 scraping code for 1 of the 3 websites

EnergyBin code

```python
import datetime    #collects time and day
import requests    #importing plugin
import bs4         #importing scraping plugin
import json        #importing .json file format
from requests import Session
from bs4 import BeautifulSoup as bs

d = datetime.datetime.today()
URL = 'https://members.energybin.com/partsearch?parts=used'

with Session() as s:              #inputting login credentials for EnergyBin

    site = s.get("https://members.energybin.com/")
    bs_content = bs(site.content, "html.parser")
    login_data = {"login":"*******","password":"******"}
    s.post("https://members.energybin.com/",login_data)
    home_page = s.get("https://members.energybin.com/partsearch?parts=used")

    soup = bs4.BeautifulSoup(home_page.text,"lxml")

    item = dict()

products = (soup.select(".result_row"))     #class for table data
parameters = products[3]                     #describes line entity on table

for product in products:                     #scraping item data for dictionary
 item['Timestamp'] = d.strftime('%B-%d-%Y')
 item['URL'] = URL
 item['Company'] = (parameters.select)('a')[1].text
 item['Location'] = (parameters.select)('td')[3].text.strip()
 item['Manufacturer'] = (parameters.select)('td')[5].text.strip()
 item['Part/Model'] = (parameters.select)('td')[6].text.strip()
 item['Warranty'] = (parameters.select)('td')[9].text.strip()
 item['Condition'] = (parameters.select)('td')[10].text.strip()
 item['Price'] = (parameters.select)('td')[11].text.strip()
 item['Watts'] = (parameters.select)('td')[12].text.strip()
 item['Description'] = (parameters.select)('td')[14].text.strip().replace(',','')

print(item)

with open("energybin.json","a") as outfile:    #saving (item) as .json file
        json.dump(item, outfile)
        outfile.write('\n')
```

PV and HDD Collection–
Step 3

Tools:
 - Web scraping was conducted using Beautiful Soup
 - Data was compiled and organized using pandas
 - Graphics were generated using seaborn and Matplotlib

PV and HDD Markets –
Results

- Notable Findings:
  - The useful life of PV modules are 5x longer than HDDs
  - Secondhand PV market represents 0.05% of total annual sales in comparison to 4.2% by the secondhand HDD market
  - Secondhand PV market absorbs 1% of PV waste, while the secondhand HDD market absorbs 6% of HDD waste
 - The oldest PV module for sale was from 2000 with the average being from 2013
  - The oldest HDD for sale was from 2012 with the average being from 2017

	PV	HDDs
Average lifetime	30 years (IRENA & IEA, 2016)	6 years (iNEMI, 2019)
Annual installed capacity (units)	32.4 million (IRENA & IEA, 2016)	70 million (Shehabi et al., 2016)
Annual EOL product (units)	1.5 million (IRENA & IEA, 2016)	50 million (iNEMI, 2017)
Annual used sales (estimated units)	10-25 thousand	1.5-3 million

	PV				HDDs			
	Mean	Std	Min	Max	Mean	Std	Min	Max
Capacity (Wp/TB)	264	48	75	370	4.4	3.6	0.32	16
Year produced	2013	3.77	2000	2019	2017	2	2012	2020
Used PPW/PPT ($)	0.23	0.13	0.1	0.6	33.75	16.25	13.75	81.47
New PPW/PPT ($)	0.72	0.17	0.4	1.26	38.74	13.55	30	100
Used/new price ratio	0.31	0.21	0.11	1.14	0.92	0.47	0.19	2.34

PV and HDD Markets–
Results Cont.

Key takeaways:

- There is a small trend of secondhand/new price ratios in PVs with time, but variability also increases
- Website pricing structure is unrelated to the other websites
- No relationship between average secondhand PPW (blue line) and average new PPW (orange line).
- Average price ratio for PV is more erratic than average price ratio for HDDs over time
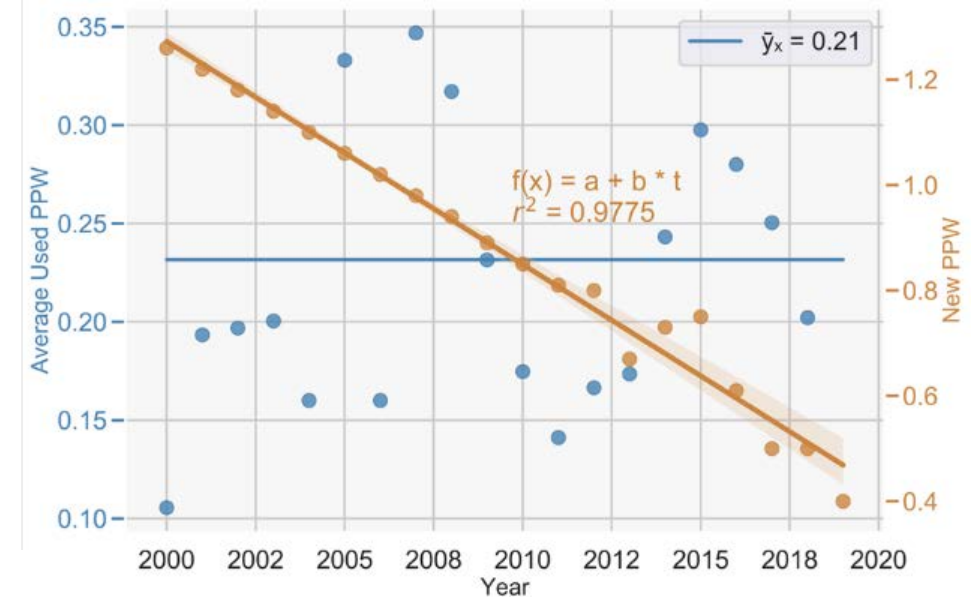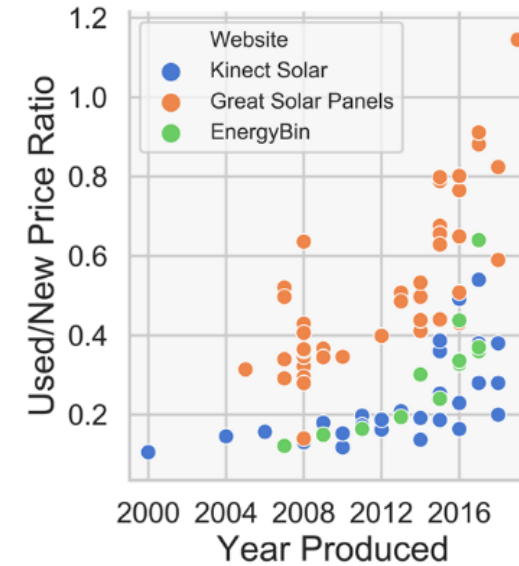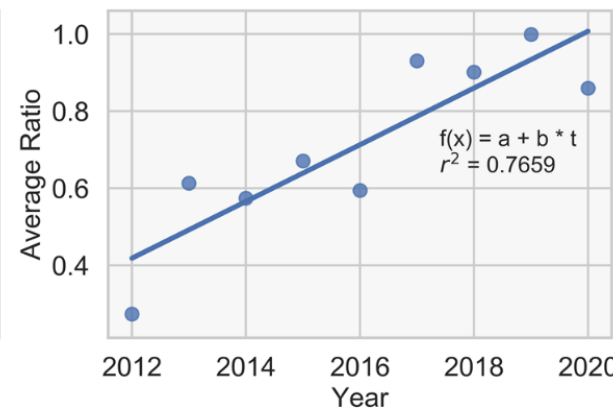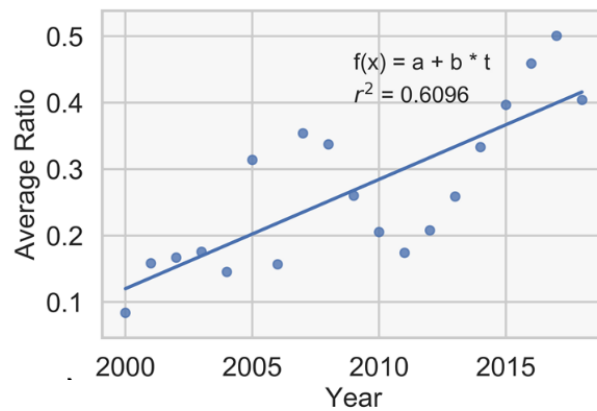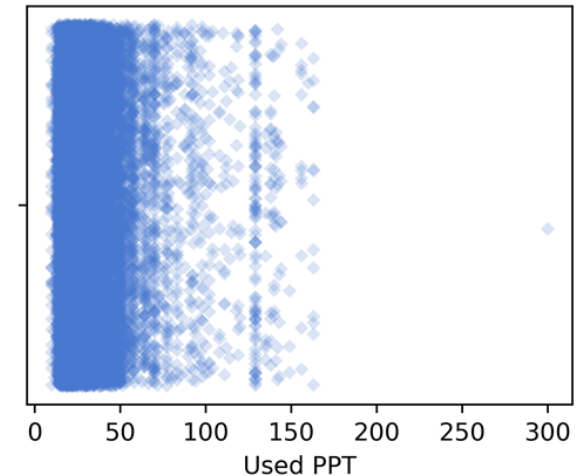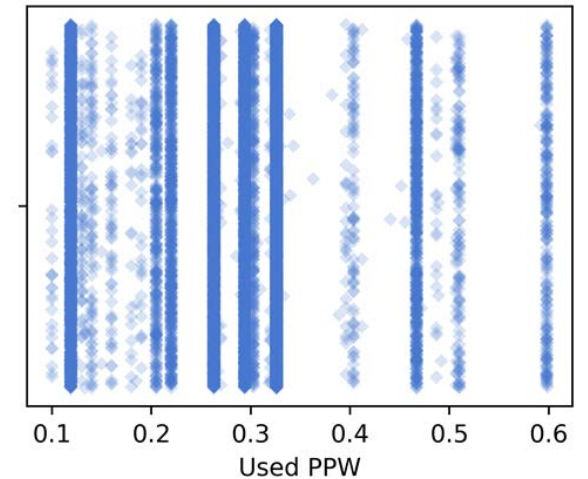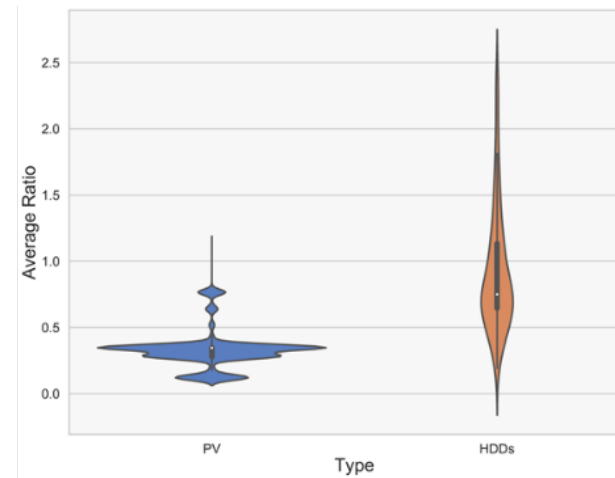
Expanded Data:

- Secondhand PV modules are typically sold at less than the new module price while HDDs have more price variability

PPW

- Secondhand PPW for PV modules has greater variability

HDD

- Secondhand PPT for HDDs have higher density below $50 with decreasing density with price increase

Key takeaways & further steps

- The secondhand PV market is extremely underdeveloped, and no correlations were drawn between PPW and any descriptive characteristic (e.g., year produced, manufacturer, cell type, country etc.)

- The comparison of the PV and HDD market help show what correlations exist in further developed secondhand markets.

- Next steps:
  - Further research would lead to better estimations regarding the secondary markets' sizes as new data is available
  - Compare other emerging secondary markets to see what similarities exist to help contribute to the ABM

Thank you!

www.nrel.gov

Liam.Watts@nrel.gov

NREL/PR-6A20-80485