Plastic Waste Forecasting and Potential Application in Renewable Energy System and Building for Environmental Footprint Mitigation




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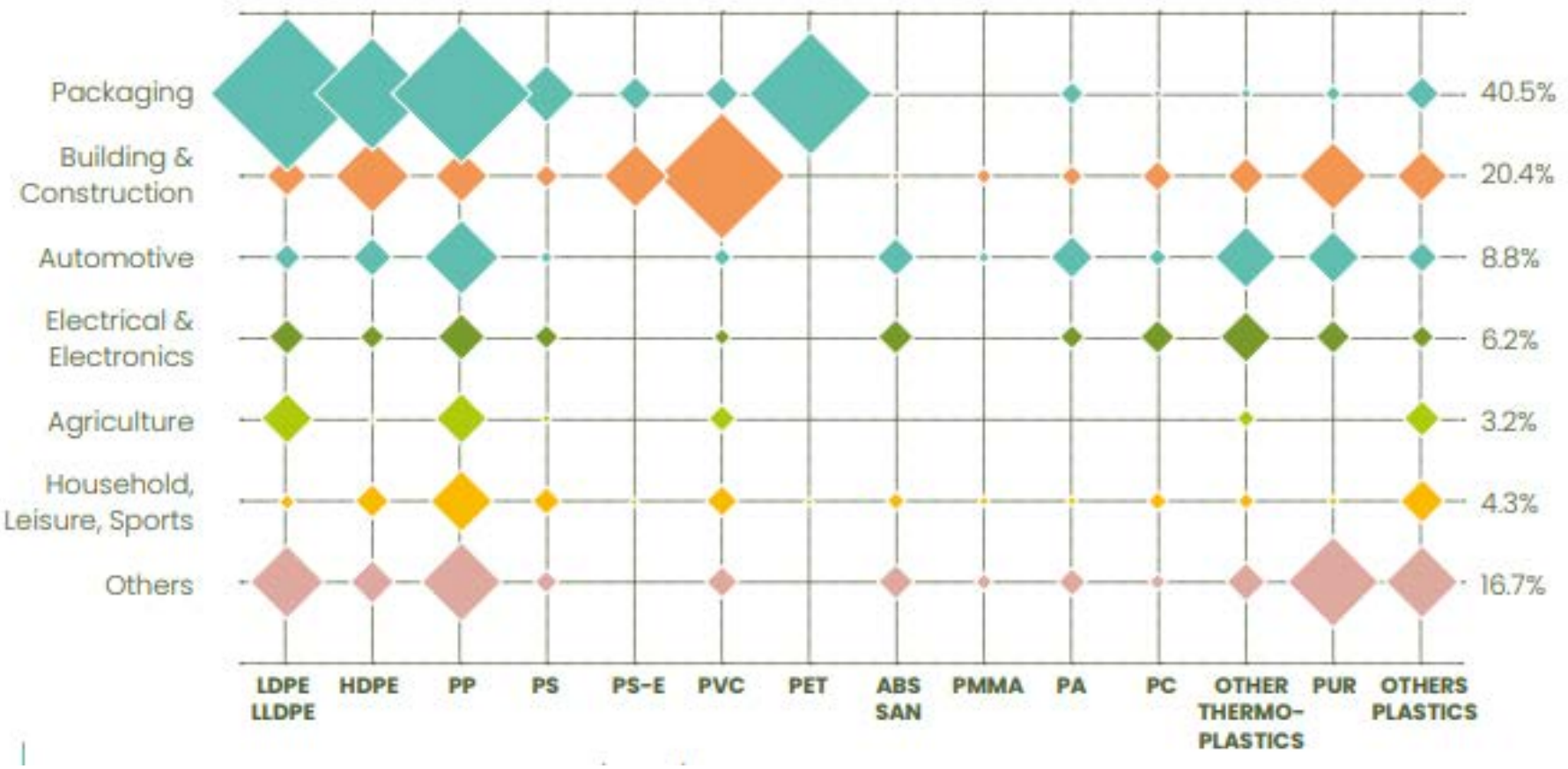
9th International Conference on Sustainable Solid Waste Management, 15-18 June 2022, Corfu, Greece

Plastic By Segment and Polymer



Packaging and **Building & Construction** by far represent the largest end-use markets

<plasticseurope.org/wp-content/uploads/2021/12/Plastics-the-Facts-2021-web-final.pdf>

Aim and Purpose

- To build a neural network model to **forecast plastic waste generation** of the EU-27 in 2030 and **interpret the relationship with predictors**
- Explore the **wider application** of **recycled plastic waste** (e.g. for building, energy system) for further **environmental footprint mitigation**

- Recognise causalities to develop effective countermeasures
- Inform decision–making and develop data-driven strategies

Assessment Framework

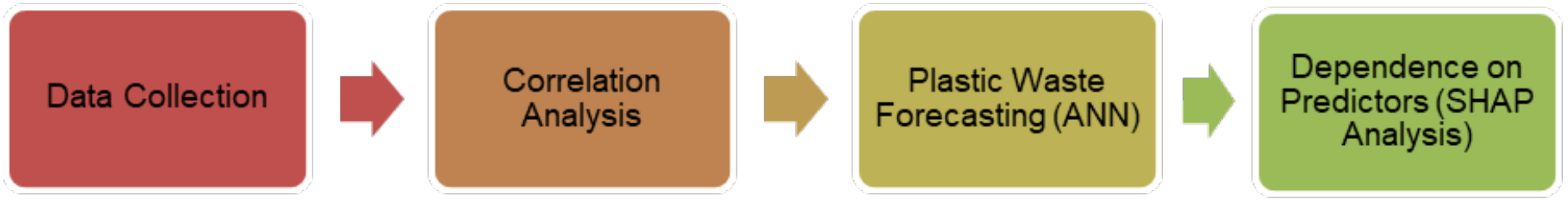
Eurostat Statistic Database

Pearson correlation

The closer the values are to −1 or 1, the stronger the linear correlation

Artificial Neural Network (ANN)

9:1 ratio between training and testing data



SHapley Additive exPlanations

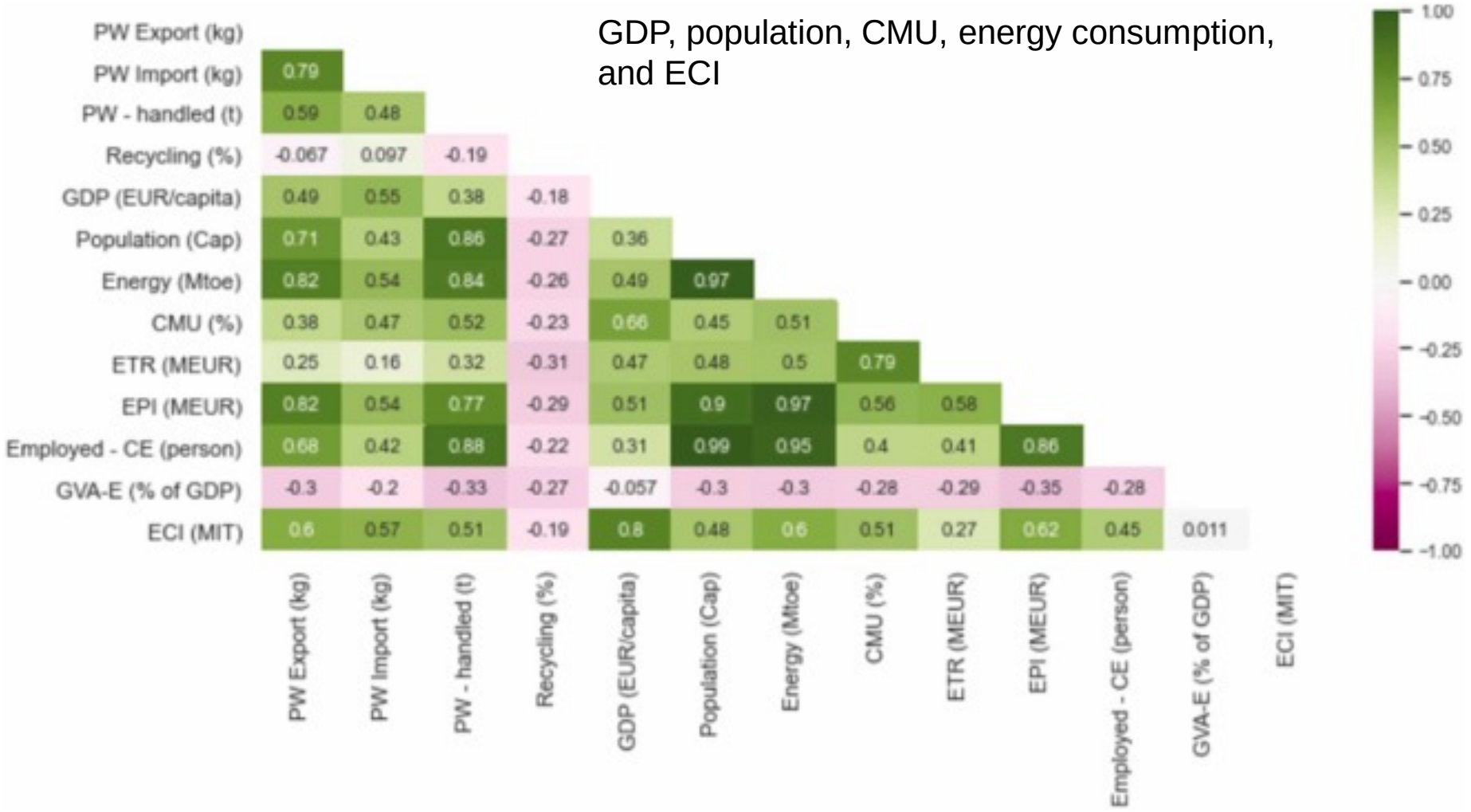
- Interpret black box or machine learning model based on cooperative game theory
- Measures the impacts of features by considering the interaction with other variables

Built-in Jupyter notebook, Version 6.3.0 (Jupyter, 2021), using Python programming language

Fan, Y.V., Jiang, P., Tan, R. R., Aviso, K. B., You, F., Zhao, X., Lee C.T., Klemeš, J. J. (2021). Forecasting plastic waste generation and interventions for environmental hazard mitigation. Journal of Hazardous Materials, 127330.

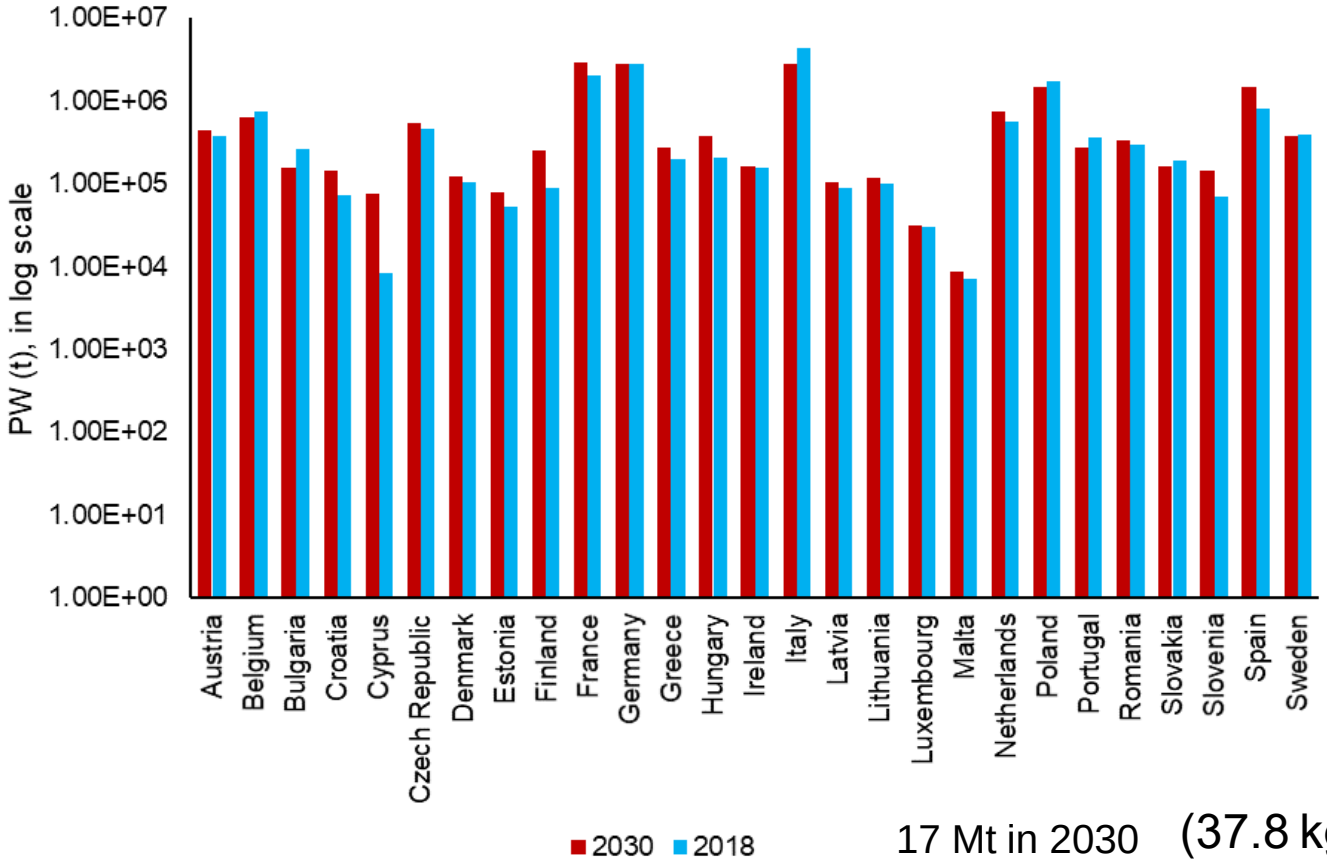
Correlation Analysis

GDP, population, CMU, energy consumption, and ECI



Fan, Y.V., Jiang, P., Tan, R. R., Aviso, K. B., You, F., Zhao, X., Lee C.T., Klemeš, J. J. (2021). Forecasting plastic waste generation and interventions for environmental hazard mitigation. Journal of Hazardous Materials, 127330.

Forecasted Plastic Waste



However, by Kaza et al. (2018)

Europe and Central Asia = 56.94 kg/cap/y (GDP as predictor)

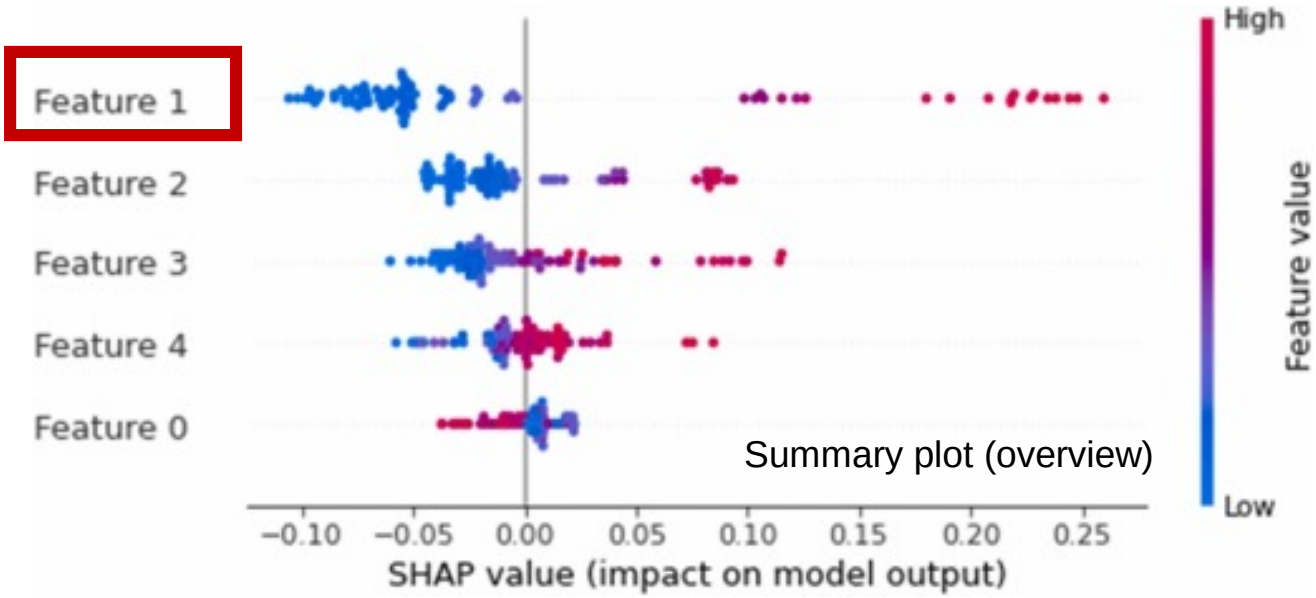
17 Mt in 2030 (37.8 kg/cap/y in our study)

- Most countries expect a typical waste management trend, an increment in plastic waste.
- Except Belgium, Bulgaria, Germany, Italy, Poland, Portugal, Slovakia and Sweden. They are estimated to have a slight decrease in plastic waste generation.

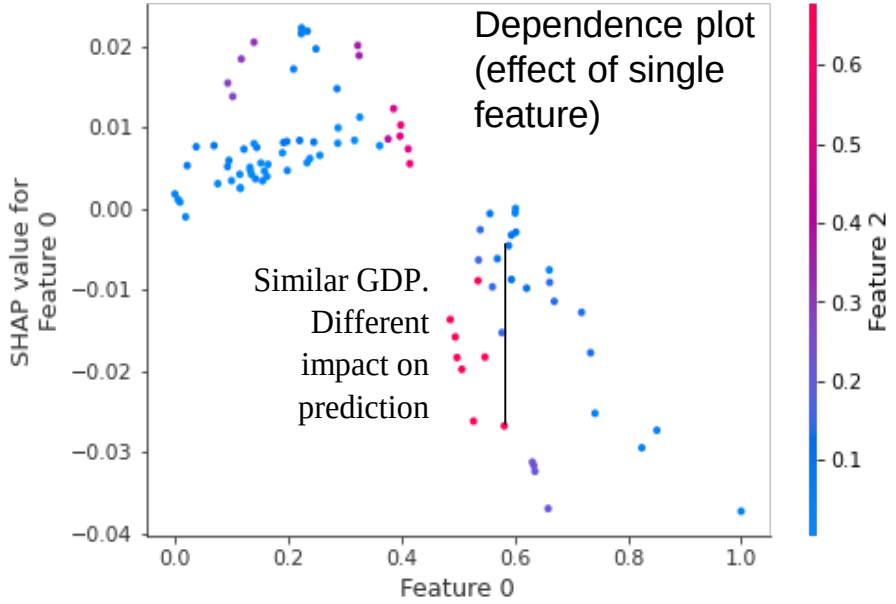
Fan, Y.V., Jiang, P., Tan, R. R., Aviso, K. B., You, F., Zhao, X., Lee C.T., Klemeš, J. J. (2021). Forecasting plastic waste generation and interventions for environmental hazard mitigation. Journal of hazardous materials, 127330.

SHAP Analysis

what is driving the predicted plastic waste amount



- Feature 0 = GDP (EUR/capita),
- Feature 1 = Population (capita),
- Feature 2 = Final Energy Consumption (Mtoe),
- Feature 3 = Circular Material Use Rate (%),
- Feature 4 = Economic Complexity Index.



Scenarios – Environmental Assessment

Scenario 1 = **2018**

- Plastic waste of EU-27 in 2018 = 16.77 Mt
- Recycling rate = 32.5%
- Energy recovery = 42.6%, Landfill = 24.9%

Scenario 2 = 2030 (I0), T (baseline)

- Plastic waste of EU-27 in 2030 = **17.00 Mt** (Predicted in this study based on ANN model)
- Recycling rate = 55% (Average target set by EU-27)
- Energy recovery rate = 42.6%, Landfill = 2.4%

Scenario 3 = 2030 (I1)

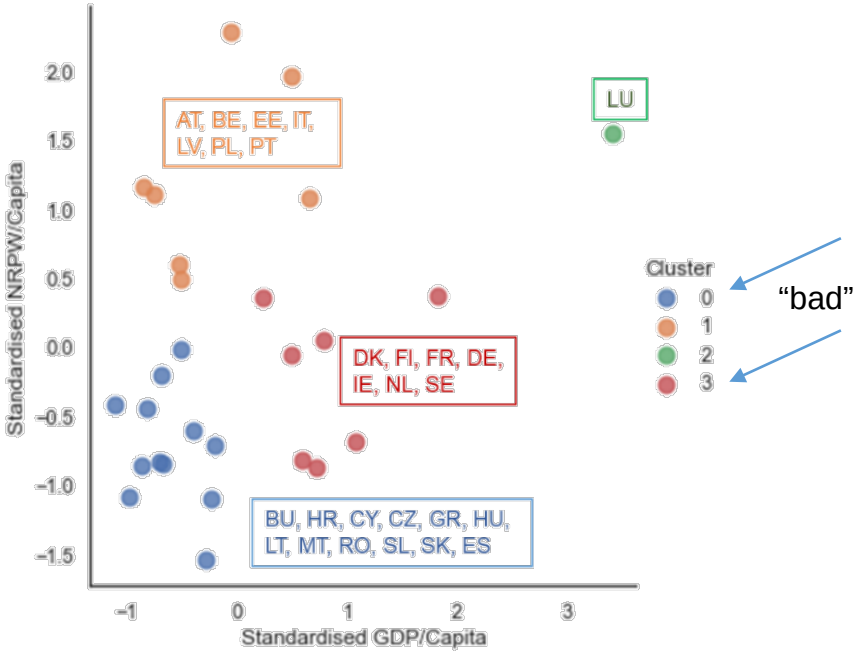
- Plastic waste of EU-27 in 2030 = **15.51 Mt** (Waste reduction enforced in clustered group 1 and 2)
- Recycling rate = 55%
- Energy recovery rate = 42.6%, Landfill = 2.4%

Scenario 4 = 2030 (I2)

Plastic waste of EU-27 in 2030 = 15.51 Mt
Recycling rate = 50% (5% less than targeted)
Energy recovery rate = 47.6%, Landfill = 2.4%

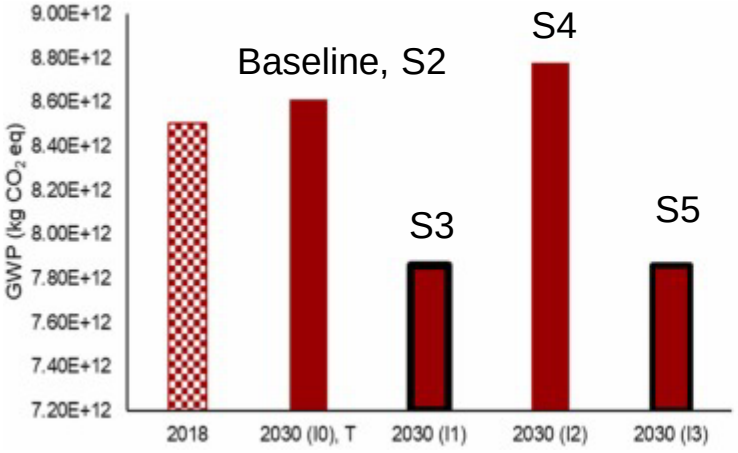
Scenario 5 = 2030 (I3)

Plastic waste of EU-27 in 2030 = 15.51 Mt
Recycling rate = 50% (5% less than targeted)
Energy recovery rate = 42.6%, Landfill = 7.4%

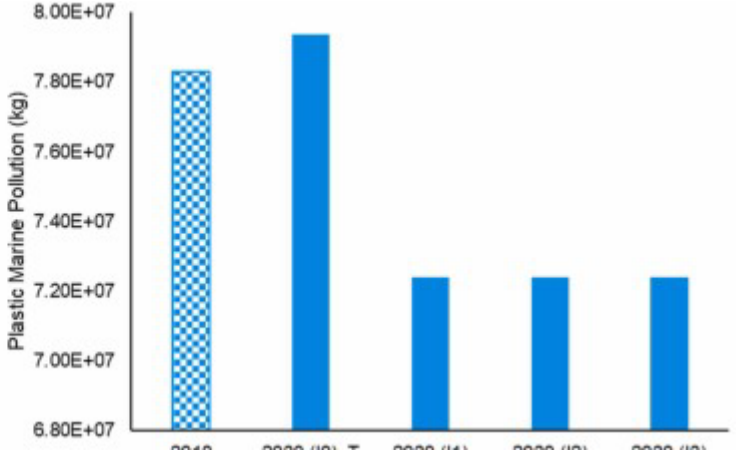


Main Results

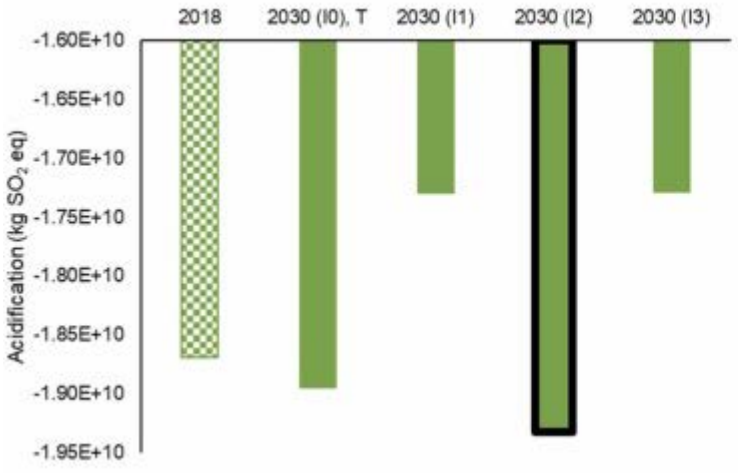
Environmental Performance



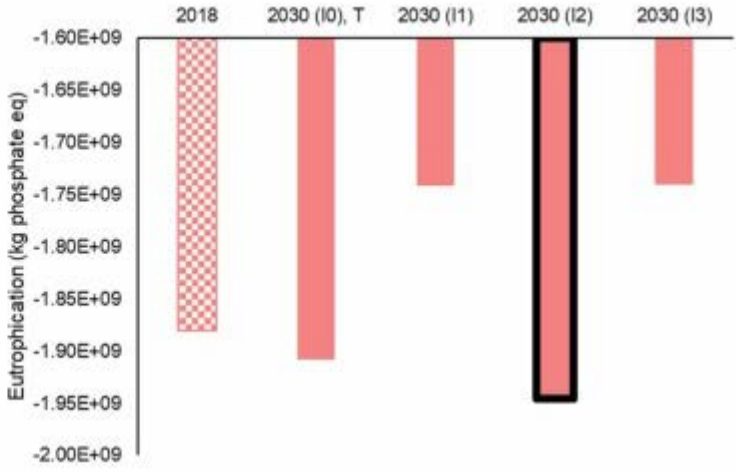
Global Warming Potential



Plastic Marine Pollution



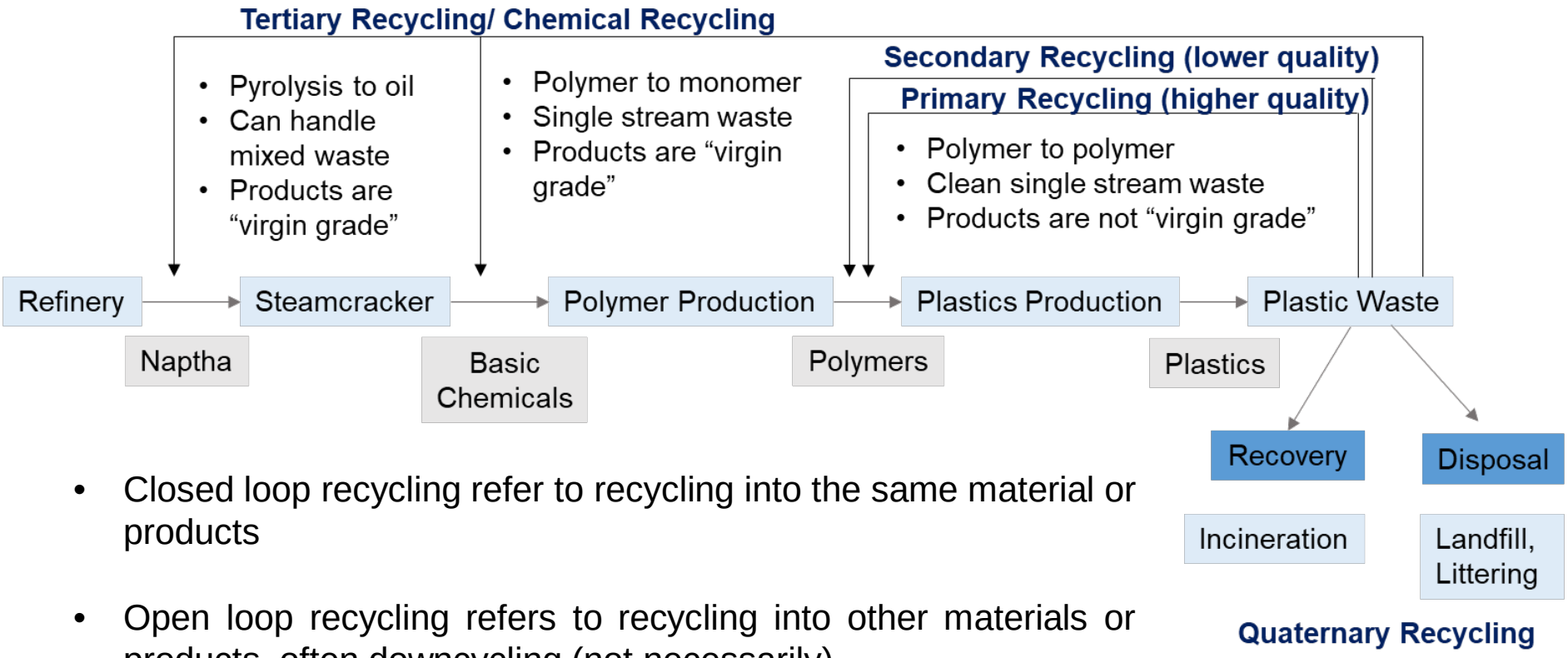
Acidification Potential



Eutrophication Potential

Beyond WtE and Primary Recycling

Accounting in our work: down cycling as categorised in the database and widely implemented, Future….

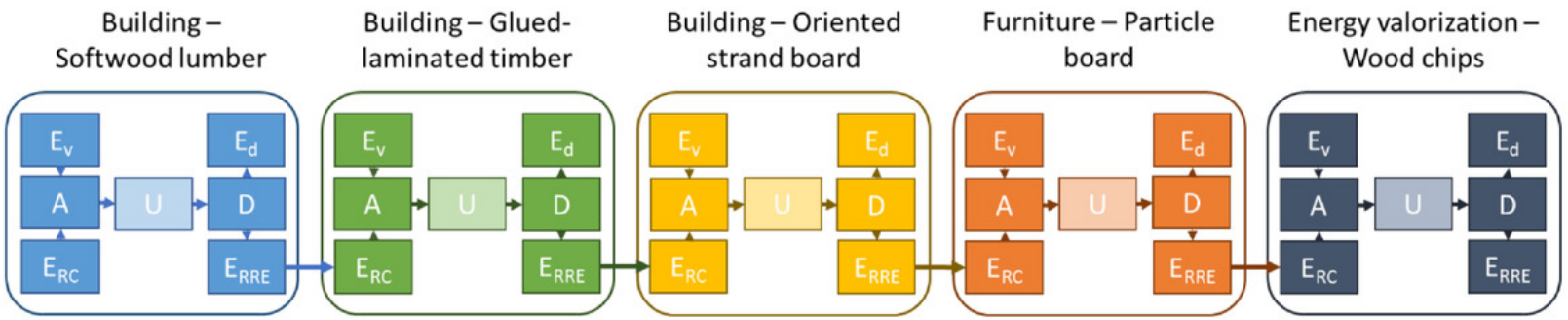


- Closed loop recycling refer to recycling into the same material or products
- Open loop recycling refers to recycling into other materials or products, often downcycling (not necessarily)

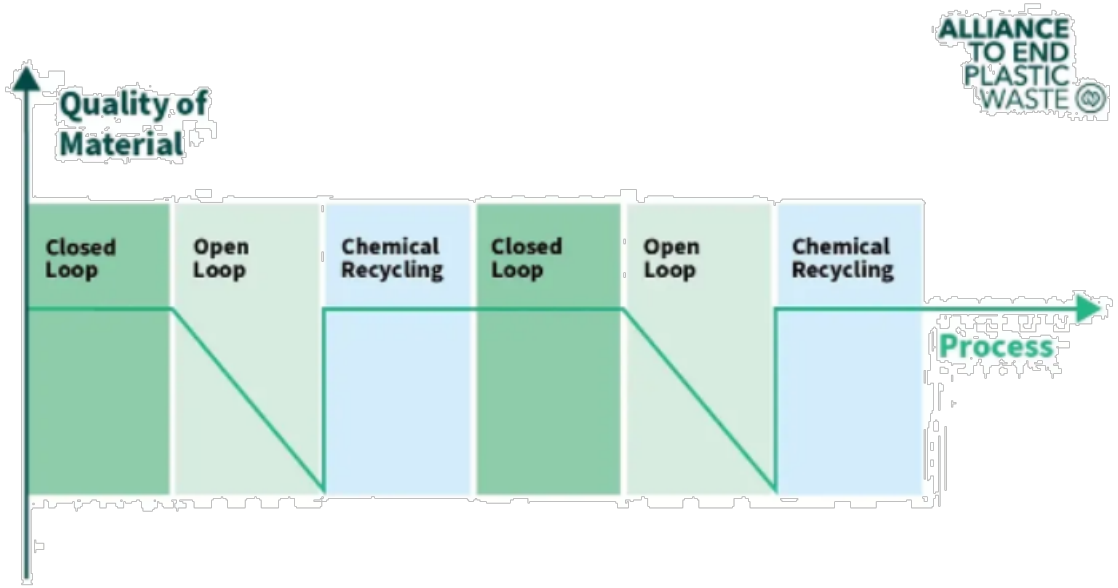
Fan YV*, Čuček L, Klemeš JJ, Vujanovic A, Varbanov PS, 2022. Life Cycle Assessment Approaches of Plastic Recycling with Multiple Cycles: Mini Review. (Submitted to Chemical Engineering Transactions).

Cascade Utilisation Before Direct Energy Valorisation

Wood



Plastics



Tanguay, X., Essoua Essoua, G. G., Amor, B. (2021). Attributional and consequential life cycle assessments in a circular economy with integration of a quality indicator: A case study of cascading wood products. Journal of Industrial Ecology, 25(6), 1462-1473.
<endplasticwaste.org/en/our-stories/notion-of-cascade-recycling>

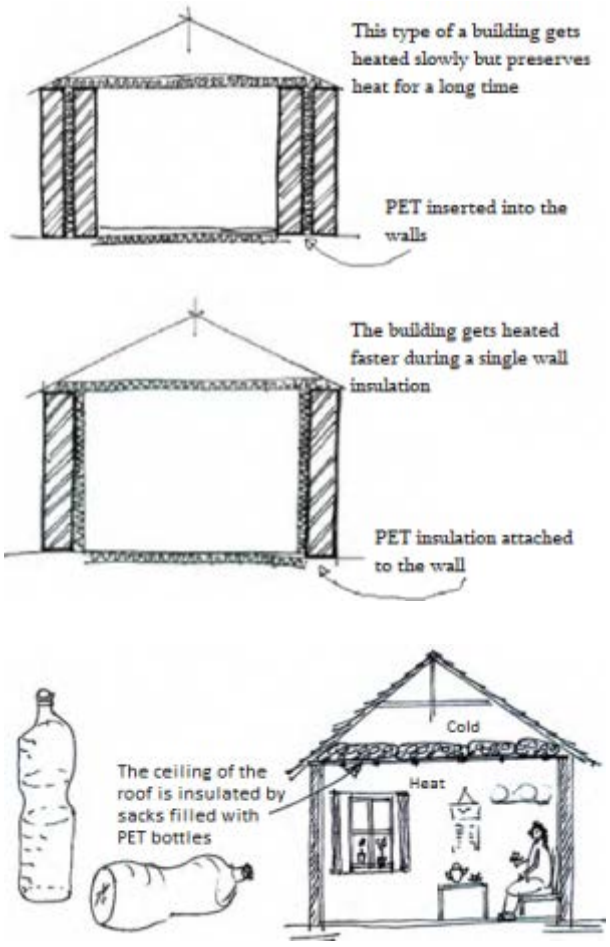
Plastic Waste for Solar Pavement

- The frame of the product is made out of plastic waste that cannot be recycled
- No new plastic materials are used for its manufacturing.
- Walkable, green building material; capable of powering buildings and electronic devices.
- One solar panel unit provides about 20 W.
- 20-30 m^2 can provide enough energy for a family home in a Hungarian climate.

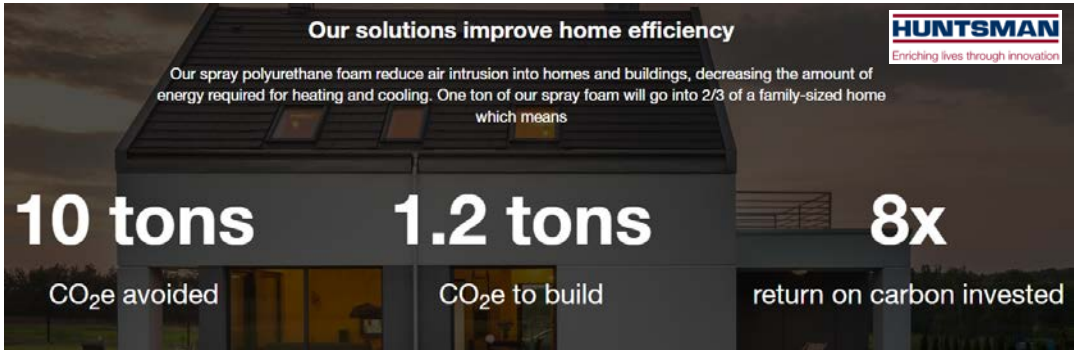
Hu, H., Vizzari, D., Zha, X., Roberts, R., 2021. Solar pavements: A critical review. Renewable and Sustainable Energy Reviews, 152, 111712.

https://platiosolar.com/

Plastic Waste for Insulation



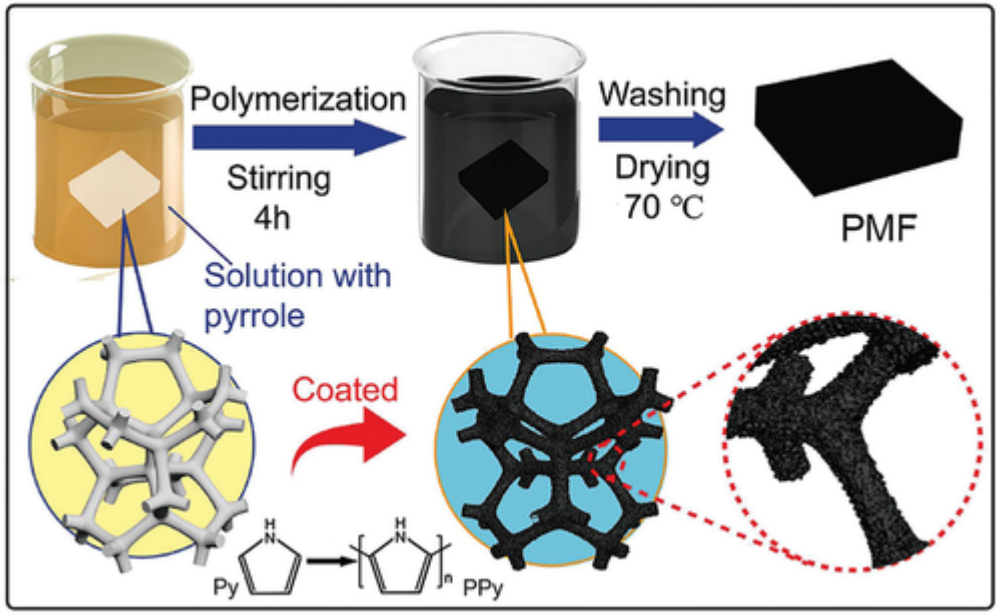
Recycling (Combines mechanical and chemical) complex (low quality) pet packaging (PET) in order to turn it into insulating foam (polyols).



$5x10^9$ PET bottles (500mL) to manufacture 131 kt of TEROL® polyester polyols

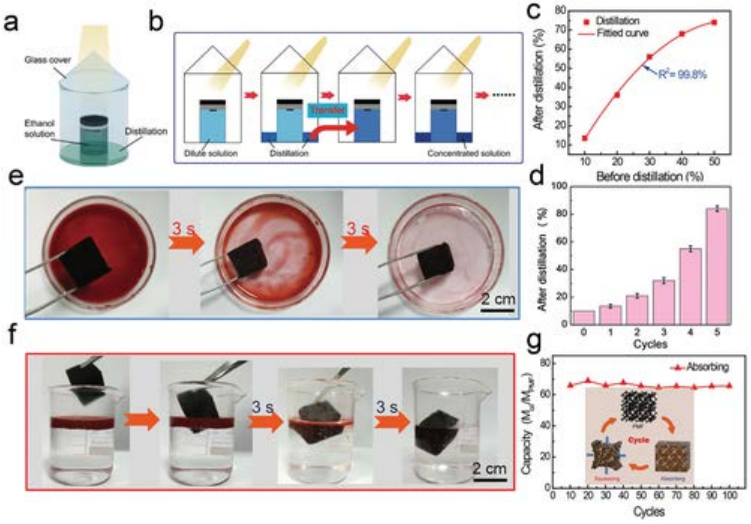
Caniato, M., Cozzarini, L., Schmid, C., Gasparella, A. (2021). Acoustic and thermal characterization of a novel sustainable material incorporating recycled microplastic waste. Sustainable Materials and Technologies, 28, e00274.
<environment.cenn.org/waste-management/publications/improving-thermal-insulation-use-plastic-waste/#_ftn3>
<www.soprema.com/en/article/news/sopraloop-a-process-that-turns-plastic-waste-into-insulation>
<www.huntsman.com/sustainability/our-solutions/article/6867/transforming-plastic-waste-into-energy-saving-insulation>

Polymeric Foam Waste into Solar Energy Harvesters



poly melamine–formaldehyde foam

Energy-efficient solar-powered water purification, ethanol distillation, and oil absorption

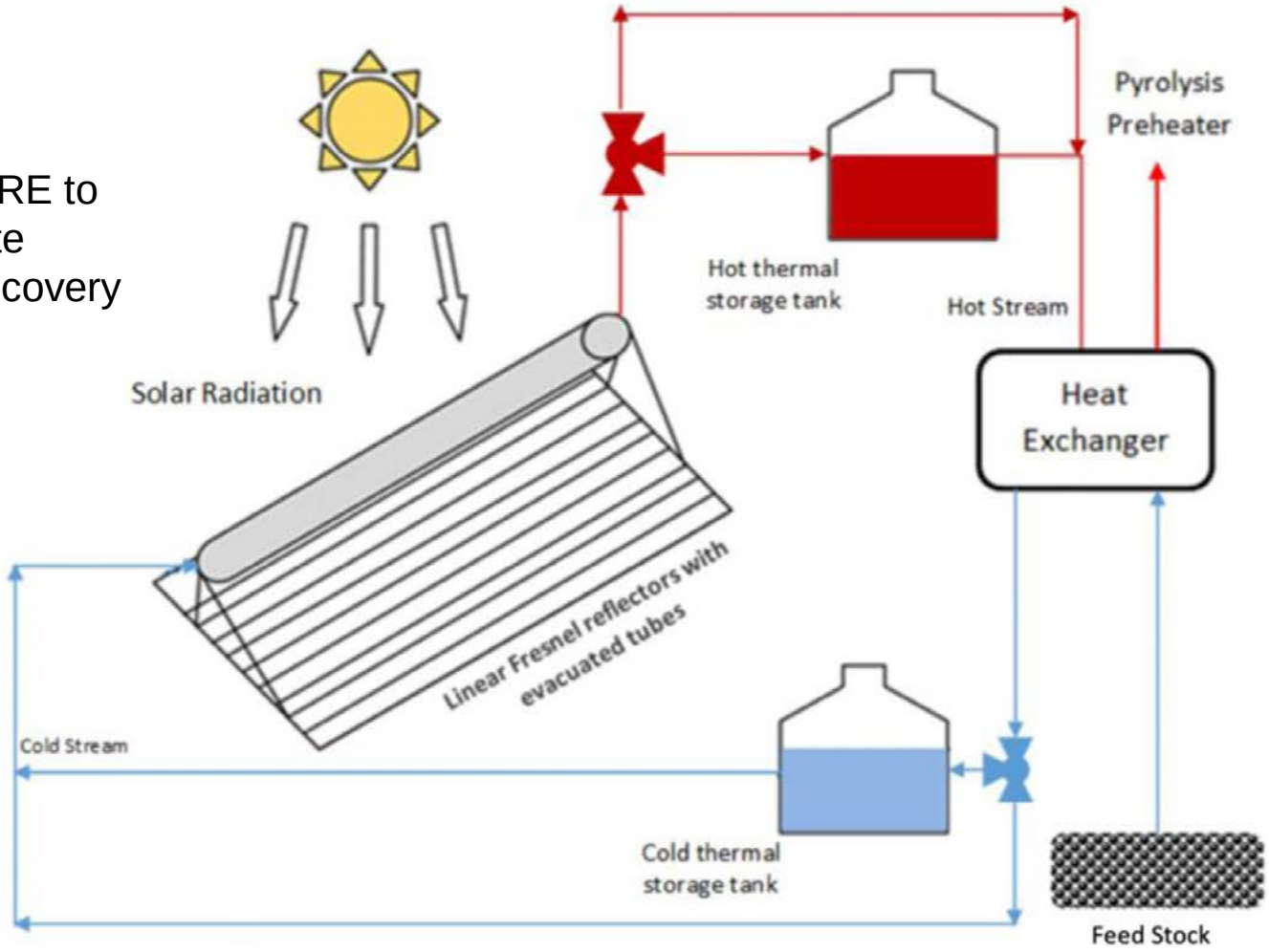


Example of oil absorption

Gong, F., Li, H., Yuan, X., Huang, J., Xia, D., Papavassiliou, D. V., Ok, Y. S., 2021, Recycling Polymeric Solid Wastes for Energy-Efficient Water Purification, Organic Distillation, and Oil Spill Cleanup. Small, 17(46), 2102459.

Concentrated Solar Driven Pyrolysis

Integrating RE to plastic waste recycling/recovery



Future work: to include more possibilities and integration in mitigating the environmental footprint of plastic value chain

Hamilton, J., Seyedmahmoudian, M., Jamei, E., Horan, B., Stojcevski, A., 2020. A systematic review of solar driven waste to fuel pyrolysis technology for the Australian state of Victoria. Energy Reports, 6, 3212-3229.

Conclusion

- Plastic waste generation in EU-27 is expected to reach **17 Mt/y in 2030** (37.8 kg/cap/y)
- Influence of **population** is still dominant – plastic is still “irreplaceable”
- Some of the environmental impacts cannot be reduced merely by targeting a **55% recycling rate**
- **Cascade** recycling or **upcycling** before WtE
- Improved **LCA Modelling** (allocation) of plastic recycling

Acknowledgement

The financial support from the RESHeat project that has received funding from the European Union HORIZON 2020 research and innovation programme under grant agreement No 956255" and GACR (Grant Agency of the Czech Republic) under No. 21-45726L and from the Slovenian Research Agency for project No. J7-3149 are acknowledged.

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SPIL

The 6th Sustainable Process Integration Laboratory (SPIL) Scientific Conference

14 – 15 November 2022 (Hybrid), Brno, Czech Republic

- **The Start of Abstract Submission:** 10 March 2022
- **Abstract Due:** 31 September 2022
- **The Start of Registration:** 1 May 2022
- **Early Bird Registration Due:** 15 August 2022

REGISTRATION FEES

Early Bird Registration

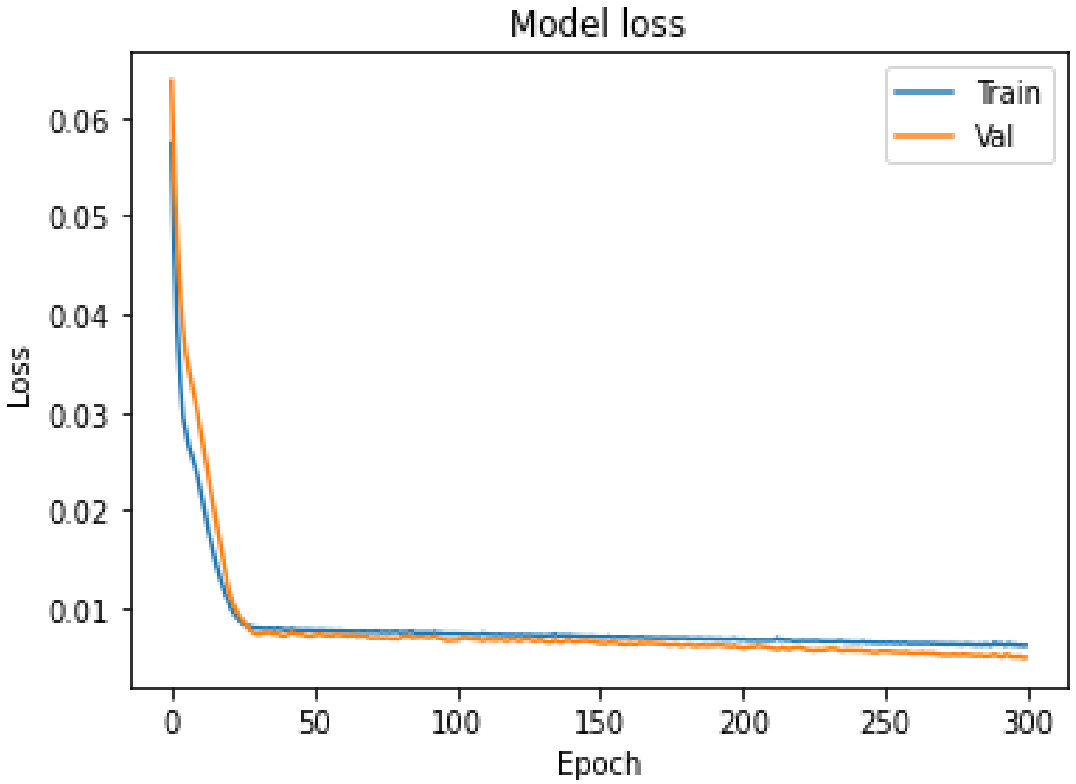
- Regular Presenter (Onsite) = 150 EUR
- Regular Presenter (Online) = 95 EUR
- Reduced Fees for Student Presenter (Onsite) = 110 EUR
- Reduced Fees for Student Presenter (Online) = 60 EUR

After 15 August 2022

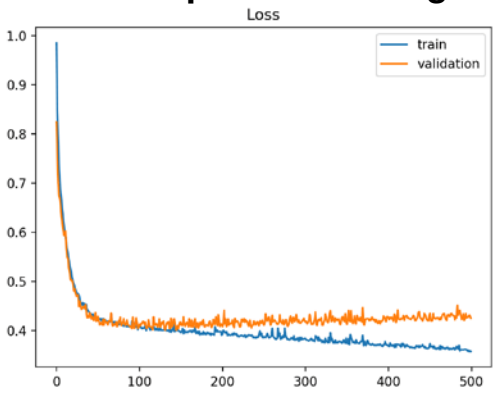
- Regular Presenter (Onsite) = 170 EUR
- Regular Presenter (Online) = 120 EUR
- Reduced Fees for Student Presenter (Onsite) = 130 EUR
- Reduced Fees for Student Presenter (Online) = 80 EUR

https://conferencespil.com/spil-2022/

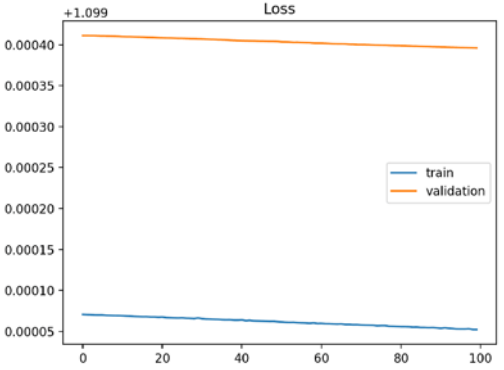
ANN Learning Curve



Example: Overfitting



Example: Under fitting



Learning curves do not show a significant trend of overfitting (training loss continues to decrease with experience, validation loss decrease to a point and increase) and underfitting (training loss remains flat, training loss continues to decrease)