

Thermodynamic Lifespan Modelling of Recycled PET under Circular Use Scenarios

Alexander Oshioke Ugbodaga

University of Lagos

Modupe A. Onitiri

University of Lagos

Ismail Ladele Ladipo

iladipo@hct.ac.ae

Higher Colleges of Technology

Research Article

Keywords: Circular economy, Mechanical properties, Crystallinity, Recycling of polymers, Modelling, Thermodynamic degradation

Posted Date: October 7th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10636573/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Thermodynamic Lifespan Modelling of Recycled PET under Circular Use Scenarios

Alexander Oshioke Ugbodaga^a, Modupe A. Onitiri^a, Ismail Ladipo^{b,*}

^a*Department of Mechanical Engineering, University of Lagos, Nigeria*

^b*Faculty of Engineering Technology and Science, Higher Colleges of Technology, Sharjah, United Arab Emirates*

Abstract

This study establishes a novel quantitative framework determining the precise thermodynamic and physical boundaries of mechanical Polyethylene Terephthalate (PET) recycling across multiple life cycles. Lacking direct empirical metrics, cumulative entropy generation and energy dissipation are systematically derived as standardized proxy indicators from a curated 83-record dataset spanning repeated processing, fatigue, and intrinsic viscosity degradation. A weighted PET Lifespan Index (PLI) is introduced to model material degradation utilizing a validated 0.50 threshold boundary. The framework successfully classifies 24 dataset records as optimal for high-grade reuse (PLI 0.75–1.00), 38 records viable for traditional mechanical recycling (PLI 0.50–0.74), and 2 records relegated to downcycling tracks (PLI 0.25–0.49). Conclusively, mechanical recycling is not thermodynamically neutral; processing, fatigue, and thermal aging incrementally consume the polymer's finite lifespan. This model bridges macromolecular mechanics and life-cycle optimization to define precise, quantifiable thermodynamic limits for plastic circularity.

Keywords: Circular economy, Mechanical properties, Crystallinity, Recycling of polymers, Modelling, Thermodynamic degradation

*Corresponding author: Dr. Ismail Ladipo, Faculty of Engineering Technology and Science, Higher Colleges of Technology, Sharjah, United Arab Emirates. Email: iladipo@hct.ac.ae

Email addresses: 210404541@live.unilag.edu.ng (Alexander Oshioke Ugbodaga), monitiri@unilag.edu.ng (Modupe A. Onitiri), iladipo@hct.ac.ae (Ismail Ladipo)

1. Introduction

Polyethylene terephthalate (PET) is one of the most widely used thermoplastic polymers, particularly in packaging, bottles, textile fibers, sheets, films, and additive manufacturing feedstock. Its high strength, chemical resistance, transparency, and processability make it a cornerstone of modern circular economy strategies. Ideally, PET waste is collected, cleaned, and processed through mechanical recycling (bottle-to-bottle), or repurposed into fibers, extruded sheets, composites, or 3D-printing filaments [1, 2].

However, the recycling of PET does not maintain its original structural integrity indefinitely. Molecular degradation is incrementally driven by repeated heating, extrusion, drying, melting, cooling, mechanical loading, UV radiation, humidity, and contamination. These cumulative stresses manifest as a reduction in intrinsic viscosity and molecular weight, increased melt flow, altered crystallinity, decreased tensile strength, embrittlement, and loss of processing stability [3, 4].

A significant limitation in current circular PET assessment is that many studies define recycling potential primarily through material recovery rates, environmental life-cycle assessments, or basic process feasibility. Fewer studies directly quantify the thermodynamic penalty associated with repeated use cycles. In thermodynamic terms, every recycling loop involves irreversible processes. Heat transfer, mechanical deformation, molecular chain scission, viscous dissipation, and crystallization rearrangement generate entropy and progressively consume the polymer’s remaining useful lifespan [5, 6].

Consequently, recycled PET should be understood not only as a reclaimed material but as a polymer with a diminishing thermodynamic lifespan. While circularity remains a vital objective, it is inherently bounded by physical degradation limits. A PET batch may remain suitable for high-grade reuse after limited reprocessing, but it will eventually necessitate downcycling or low-value recovery once cumulative degradation exceeds a critical thermodynamic threshold [6, 7].

This study establishes a thermodynamic lifespan modelling framework for recycled PET under circular use scenarios. Moving beyond isolated laboratory testing, this research utilizes a curated secondary dataset derived from extensive peer-reviewed literature on PET fatigue, ageing, reprocessing, and thermal cycling. Our aim is to convert these literature-based degradation indicators into standardized thermodynamic proxies and to classify PET circular-use viability through a novel PET Lifespan Index (PLI).

The objectives of the study are to:

- Construct a reusable secondary dataset from peer-reviewed PET degradation and recycling studies;
- Identify thermodynamic degradation proxies linked to fatigue, thermal exposure, ageing, and energy dissipation;
- Calculate entropy-generation and energy-dissipation proxy values where direct calorimetric data are absent;
- Develop a PET Lifespan Index (PLI) for standardized circular-use classification;
- Interpret PET circularity as a thermodynamically constrained degradation process.

2. Experimental Section

2.1. Dataset Design

The study adopts a literature-based constructed dataset approach. Numerical values were extracted from published studies on PET and recycled PET, including studies on repeated thermo-mechanical processing, bottle-grade PET recycling, riverine PET ageing, multilayer PET tray recycling, fatigue performance of recycled opaque PET, thermo-oxidative ageing, intrinsic viscosity retention, crystallinity development, and mechanical property degradation.

The raw records for PETs, after validation and merging, are now stored in the constructed workbook (see Table 1). The dataset contains original parent rows, secondary data that has been accepted, auxiliary property rows, and context rows. The core model contains the necessary quantitative information in the rows to compute thermodynamic or degradation proxy values. The rows that represent general information about a circular economy context, non-PET systems or theoretical are excluded. The entropy frameworks that didn't include numerical values for PET were only kept as background references and quantitative PLI interpretation was not used. The following variables are extracted: If one or more terms are not available, the weighted damage index is computed based on the available validated terms and is referred to as a proxy-based estimate. The rows that are missing information

are not removed, but kept for future processing to obtain source values for strong interpretation.

The variables that were extracted include:

- material type and sample identity;
- circular-use scenario;
- recycling or reprocessing cycle;
- processing or ageing temperature;
- fatigue loading condition;
- stress level and frequency;
- cycles to failure;
- intrinsic viscosity;
- glass transition temperature;
- melting temperature;
- crystallinity;
- density;
- tensile/yield strength;
- stress at break;
- endpoint degradation class;
- calculated entropy proxy;
- calculated energy-dissipation proxy;
- PET Lifespan Index.

Table 1: Dataset summary.

Metric	Value	Interpretation
Original parent rows retained	14	The original parent dataset rows were normalized into the expanded schema
Secondary condition rows reviewed	80	All secondary condition-data rows were screened
Secondary rows combined to form a raw dataset	69	The auxiliary rows accepted with caution
The total number of rows in the updated raw dataset	83	Parent + secondary rows (validated)
Source register entries	56	This index is a source register for parent + secondary literature rows
Fatigue proxy rows	24	Converted to cyclic entropy/energy proxy rows
Thermal ageing proxy rows	24	This was used in calculations of thermal entropy proxies
Processing or recycling proxy rows	12	This was used for circular processing (entropy proxy) calculations

2.2. Source Categories

This dataset is a combination three major source categories (see Table 2).

First, PET reprocessing and recycling papers provide information on thermal history, intrinsic viscosity loss, crystallinity change, and processing-related degradation. These include repeated reprocessing studies and circular PET quality studies such as [8, 9, 10, 11, 12].

Second, PET fatigue and ageing studies provide cyclic or endpoint degradation behavior. [13] is used as the main fatigue-life source because it provides PET-related fatigue rows with stress condition and cycles-to-failure information. [14] provides thermal-ageing and structure-property data suitable for endpoint degradation modelling.

Third, entropy and fatigue-damage framework papers provide theoretical support for entropy-based degradation modelling. These papers are not treated as direct PET experimental data unless PET-specific numerical val-

ues are available. Instead, they justify the use of entropy generation, energy dissipation, and cumulative damage as lifespan indicators.

Table 2: Key literature sources and extracted data role.

Source	Dataset role	Main values used	Entropy status
Korycki et al. (2022)	PET/rPET fatigue	Cycles to failure, stress level, fatigue endpoint	Calculated entropy/energy proxy
Panowicz et al. (2021)	PET ageing	Thermal ageing, strength and structural changes	Calculated thermal/property proxy
Gomes et al. (2025)	Reprocessed PET	Reprocessing state, IV, thermal indicators	Calculated processing proxy
Ronkay et al. (2025)	Riverine/recycled PET	Ageing and recycling quality indicators	Calculated ageing/recycling proxy
Santomasi et al. (2024)	Multilayer rPET trays	IV/molecular degradation and impurity effects	Property-loss proxy
Pinter et al. (2021)	Bottle-to-bottle recycling	Circular recycling quality retention	Property-loss proxy
Teles et al. (2025)	Open-loop rPET/AM	Open-loop processing and IV decline	Property-loss proxy

2.3. Thermodynamic Proxy Assumptions

Direct entropy-generation data are rarely reported in PET recycling studies. Therefore, this study calculates entropy-related variables as standardized proxies. The current model uses the following working assumptions:

- PET specific heat capacity: $1200 \text{ J kg}^{-1} \text{ K}^{-1}$;
- reference temperature: 298.15 K ;

- standardized strain proxy: 0.01;
- dissipation fraction: 0.10;
- PET density: 1380 kg m⁻³.

These values are used only to create comparable proxy variables. They are not presented as direct calorimetric measurements. The approach is therefore a controlled proxy framework: source papers provide the experimental degradation indicators, while thermodynamic relationships convert those indicators into comparable entropy and energy terms.

2.4. Energy Dissipation Proxy

For fatigue rows where stress amplitude and cycles to failure are available but hysteresis-loop area is not reported, a standardized mechanical energy-dissipation proxy is calculated as:

$$E_{\text{diss,cycle}} = \eta \frac{\sigma_a \varepsilon_p}{\rho} \quad (1)$$

In the above equation, the energy dissipated per cycle per unit mass ($E_{\text{diss,cycle}}$), the dissipation fraction (η) is an unknown the stress amplitude (σ_a) is known, the strain proxy (ε_p) is standardized, and PET density (ρ) is known.

The entropy proxy per fatigue cycle is then:

$$S_{\text{cycle}} = \frac{E_{\text{diss,cycle}}}{T} \quad (2)$$

where the T is absolute test temperature.

The cumulative entropy at endpoint is:

$$S_{\text{cum}} = S_{\text{cycle}} N_f \quad (3)$$

where N_f is the number of cycles to failure reported.

2.5. Thermal Entropy Proxy

For thermal ageing and reprocessing rows, a thermal energy proxy is determined based on a 1 kg PET basis as follows:

$$Q_{\text{thermal}} = C_p(T - T_{\text{ref}}) \quad (4)$$

C_p is the specific heat capacity of PET, T is the processing/ageing temperature, and T_{ref} is the reference temperature.

The entropy proxy corresponding is:

$$S_{\text{thermal}} = \frac{Q_{\text{thermal}}}{T} \quad (5)$$

This way the thermal exposure during ageing, bottle production, extrusion or reprocessing can be reported as a similar degradation variable related to entropy.

2.6. Property-Loss Function

If intrinsic viscosity, strength, crystallinity, density or other material properties are given for rows, the normalized property-loss term is computed as:

$$P_{\text{loss}} = \frac{P_0 - P_i}{P_0} \quad (6)$$

Note that P_0 stands for the initial value, and P_i is the value post ageing, processing, recycling, or fatigue. If the properties are degraded in a specific direction, like increasing crystallinity for ageing processes or increasing the melt flow rate, the direction of the degradation is reversed to make the normalized loss positive.

2.7. PET Lifespan Index

The PET Lifespan Index (PLI) was created to link the thermodynamic irreversibility with measurable material degradation. The index is based on the premise that the more the entropy generation, energy dissipation, and material property losses, the less the useful lifespan of recycled PET.

Each term is normalized with min-max normalization since it has different units for entropy, energy and material properties:

$$X^* = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad (7)$$

The normalized variables are then added together using a set of weights to create a weighted damage index:

$$D = w_S S^* + w_E E^* + w_P P^* \quad (8)$$

whereas S^* is a normalized entropy-generation proxy, E^* a normalized energy-dissipation proxy and P^* a normalized material-property-loss term.

The weighting of entropy generation is the highest as the focus of the framework is thermodynamic; energy dissipation and property loss ensure that the index is maintained to be linked to measurable PET degradation.

The PET Lifespan Index is given as:

$$PLI = 1 - D \quad (9)$$

A high PLI is indicative of more potential for use in a circular economy, while a low PLI is indicative of advanced degradation and less potential for use in a circular economy.

Table 3 below shows the variables in the thermodynamic model:

Table 3: Variables of the thermodynamic model.

Variable	Symbol	Unit	Interpretation
Energy dissipation per cycle	$E_{\text{diss,cycle}}$	$\text{J kg}^{-1} \text{ cycle}^{-1}$	Mechanical fatigue proxy
Entropy per cycle	S_{cycle}	$\text{J kg}^{-1} \text{ K}^{-1} \text{ cycle}^{-1}$	Irreversibility proxy per cycle
Cumulative entropy	S_{cum}	$\text{J kg}^{-1} \text{ K}^{-1}$	Endpoint entropy proxy
Thermal energy input	Q_{thermal}	J kg^{-1}	Thermal exposure proxy
Thermal entropy	S_{thermal}	$\text{J kg}^{-1} \text{ K}^{-1}$	Processing/ageing entropy proxy
Property loss	P_{loss}	dimensionless	Material degradation term
Damage index	D	dimensionless	Weighted degradation score
PET Lifespan Index	PLI	dimensionless	Remaining circular-use potential

Table 4: Rules for circular pathway classification.

PLI range	Circular pathway	Interpretation
0.75–1.00	Reuse / high-grade recycling	High remaining lifespan and high circular use potential
0.50–0.74	Mechanical recycling	Moderate degradation, but still can be recycled back to the same type of material
0.25–0.49	Downcycling	Some significant degradation, lower grade use recommended
0.00–0.24	End-of-life / low-value recovery	Very high degree of degradation; remaining functional life reduced to a minimum

The rules for circular pathway classification are listed out in Table 4 above.

If one or more terms is not available or is not validated, then the weighted damage index is computed from the available validated terms; this is termed a proxy-based estimate. Rows that don’t contain enough information are kept, but not used in strong interpretation until they are given more source values.

3. Results

3.1. Dataset Composition

There are 83 raw PET related records in the validated dataset. The records contain original parent data, extracted secondary data and validated proxy data. Of these, 80 condition data rows were examined in the secondary data set. Of these, 69 rows were incorporated into the new raw data, and the non-PET, context-only, and not-relevant-enough rows were not part of the main model.

The validation summary indicates that 59 primary modelling rows have been accepted, 9 rows of auxiliary properties have been accepted, 1 row has been accepted with caution, 10 rows are context-only and were not merged in the main model, and 1 row was discarded from the PET data set. This means that although the secondary data was able to be used after screening,

not all literature data was appropriate for direct thermodynamic modelling. Figure 1 shows the dataset composition by validation status.

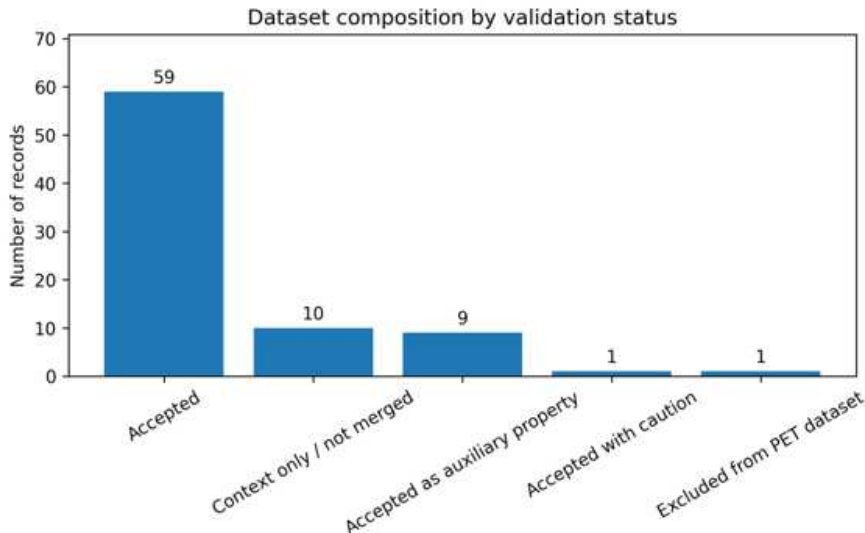


Figure 1: Dataset composition by validation status.

3.2. *Extracted Degradation Proxy Classes*

The dataset contains several degradation proxy classes. Fatigue life represented the largest single cyclic degradation class, with 24 rows based on cycles to failure. Strength-retention indicators were also important, including 12 rows based on yield stress and 12 rows based on stress at break. Ageing signatures were represented through density increase and crystallinity increase, with 4 rows each. Intrinsic-viscosity-based rows were included as molecular degradation indicators.

These proxy classes show that PET degradation is multidimensional. Mechanical fatigue does not describe the entire lifespan problem; thermal history, molecular chain degradation, crystallinity rearrangement, and property retention also contribute to circular-use viability. Figure 2 shows the proxy / endpoint type distribution in the updated dataset.

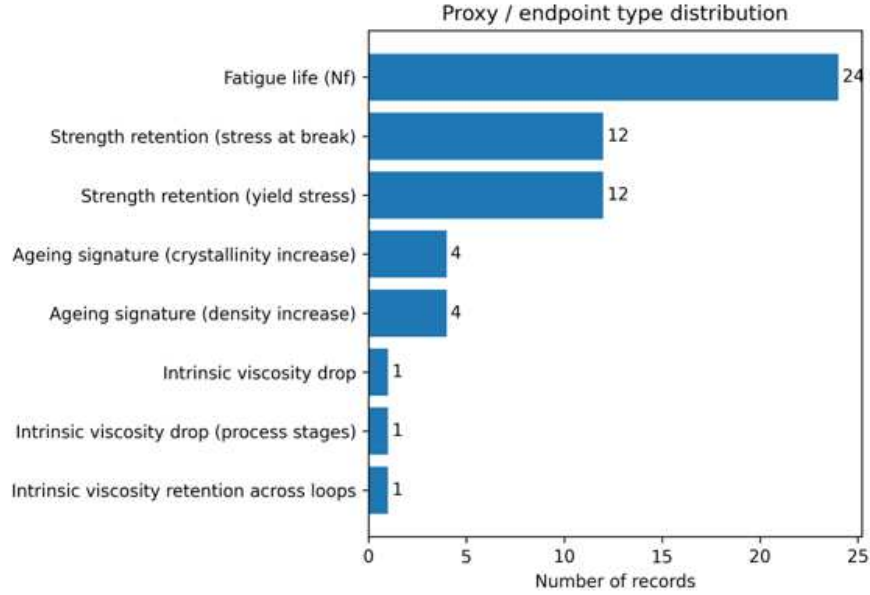


Figure 2: Proxy / endpoint type distribution in the updated dataset.

3.3. Entropy and Energy Proxy Rows

A dedicated entropy-energy proxy sheet was constructed to convert selected literature data into thermodynamic variables. The entropy proxy subset includes 24 fatigue entropy proxy rows, 24 thermal-ageing entropy proxy rows, 12 processing/recycling entropy proxy rows, and 4 intrinsic-viscosity rows treated as material property-loss indicators.

The fatigue rows use stress amplitude, standardized strain proxy, PET density, temperature, and cycles to failure to estimate energy dissipation per cycle, entropy proxy per cycle, and cumulative entropy at fatigue endpoint. The thermal-ageing and processing rows use temperature difference, PET specific heat capacity, and absolute temperature to estimate thermal energy input and entropy proxy per event.

The calculated values are not direct experimental entropy measurements. They are standardized literature-derived proxies designed to allow comparison across heterogeneous PET studies. Figure 3 shows the cumulative entropy proxy at fatigue endpoint for extracted fatigue rows.

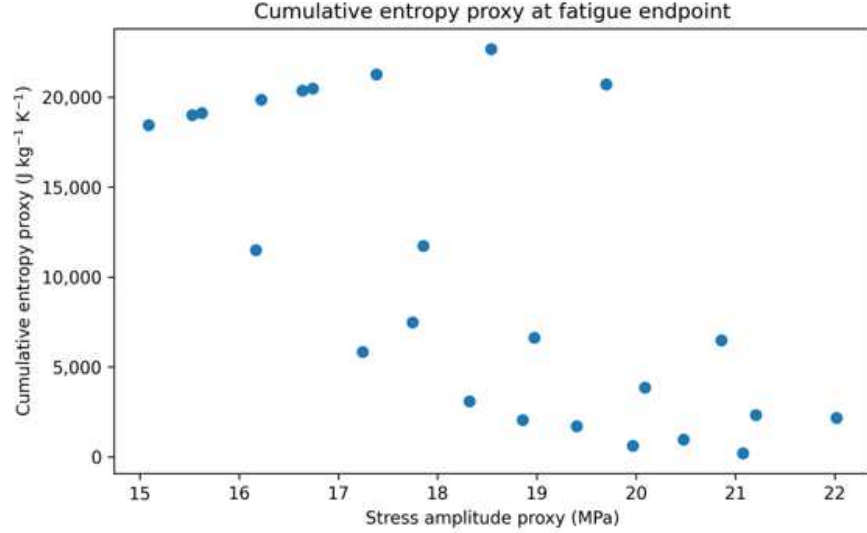


Figure 3: Cumulative entropy proxy at fatigue endpoint for extracted fatigue rows.

3.4. Circular-Use Classification and PLI Cut-off Validation

The full dataset-level circular pathway classification produced five outcome groups: reuse or high-grade recycling, mechanical recycling, downcycling, end-of-life or low-value recovery, and limited-information records. Reuse or high-grade recycling accounted for 31 rows, mechanical recycling for 13 rows, downcycling for 16 rows, end-of-life or low-value recovery for 11 rows, while 12 records were retained for traceability but excluded from strong PLI interpretation.

The weighted entropy/proxy subset produced 24 reuse/high-grade recycling records, 38 mechanical recycling records, and 2 downcycling records. No record in the weighted subset fell below the end-of-life threshold after reweighting available terms. Figure 4 validates the PLI interpretation by mapping the weighted damage index against PLI and marking the cut-off points at 0.75, 0.50, and 0.25. The most important decision boundary is $PLI = 0.50$, below which PET is no longer interpreted as suitable for normal mechanical recycling and is directed toward downcycling or lower-value recovery. Figure 5 shows the weighted PET Lifespan Index by extracted entropy/proxy record and Figure 6 shows the weighted circular pathway distribution for the entropy/proxy subset.

The summary of the result obtained for the circular pathway is shown in Table 5:

Table 5: Circular pathway result summary.

Circular pathway	Full dataset-level rows	Weighted entropy/proxy subset rows	en-
Reuse / high-grade recycling	31	24	
Mechanical recycling	13	38	
Downcycling	16	2	
End-of-life / low-value recovery	11	0	
Limited-information records	12	—	

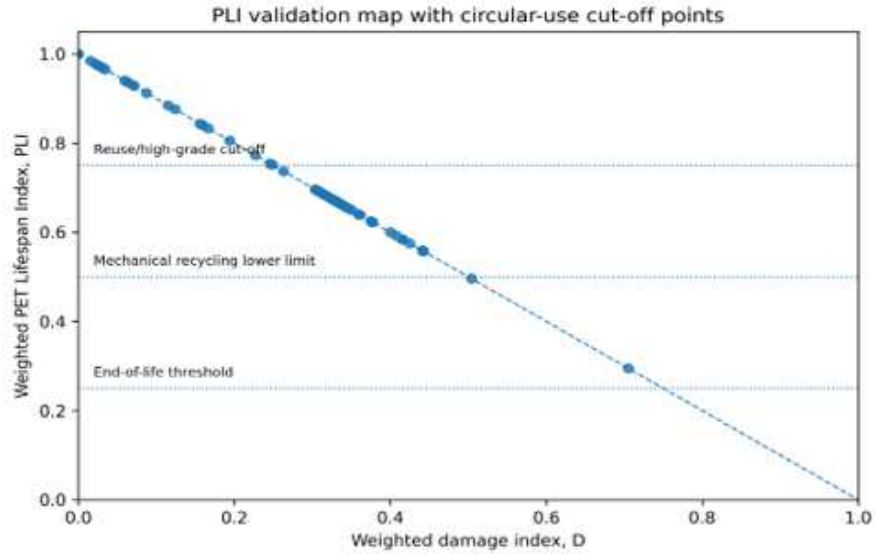


Figure 4: PLI validation map showing circular-use cut-off points.

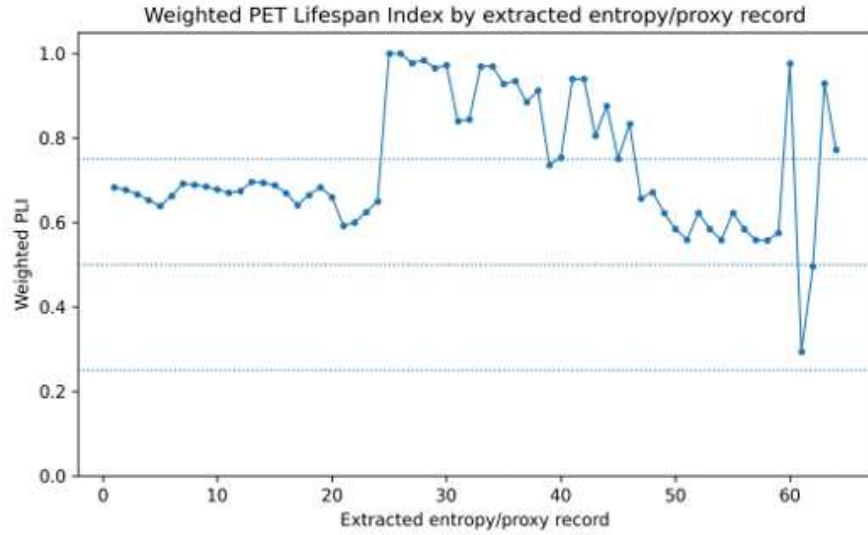


Figure 5: Weighted PET Lifespan Index by extracted entropy/proxy record.

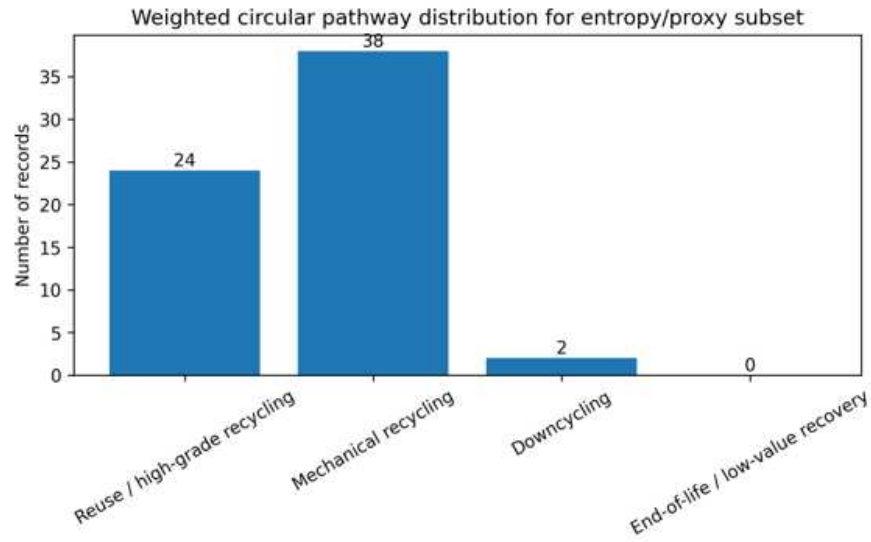


Figure 6: Weighted circular pathway distribution for the entropy/proxy subset.

3.5. Lifespan Compression Behavior

The model suggests that PET circular-use viability decreases as thermodynamic and material degradation proxies accumulate. Early reuse or

controlled reprocessing may retain sufficient lifespan for high-grade applications. However, repeated thermal exposure, fatigue accumulation, intrinsic viscosity loss, and crystallinity change reduce PLI and shift the material toward mechanical recycling, downcycling, or end-of-life classification.

This behavior is congruent with the conclusion that circular PET is performance neutral. Reuse and recycling can buy additional thermodynamic life of the material but each process uses some of the remaining life.

4. Discussion

4.1. The Use of Circular PET as a Thermodynamic Trade-off

The results demonstrate that reuse of PET can be viewed as a thermodynamic compromise. While recycling helps to keep PET in circulation, the polymer is subjected to more heat, shear, moisture, oxidation, contamination, and mechanical deformations. These processes cause non-reversible degradation, and shorten the useful life of the remaining material.

From a practical point of view, a PET sample may still be appropriate for high quality circular processing after some degree of degradation, but repeated circular process gradually diminishes its reserve of function. That is why often the circular PET strategies involve drying control, chain extenders, solid-state polycondensation, contamination management and application specific quality thresholds.

4.2. Value of Entropy Proxies in Literature-Based Modelling

One of the main contributions of this work is the conversion of literature data into proxy indicators of entropy and energy. Since most of the PET recycling studies do not report the entropy generation data directly, the proposed approach is helpful to estimate the thermodynamic degradation in PET recycling from the available data.

Data for fatigue can be converted to entropy proxy per cycle and cumulative entropy at endpoint. Thermal ageing and reprocessing data can be converted to thermal entropy proxy. The intrinsic viscosity and loss of strength can be viewed as molecular and mechanical effect of accumulated degradation as it establishes a connection between the PET recycling literature and thermodynamic life span modelling.

4.3. Implications for Circular Economy Assessment

The findings contradict the notion that re-use is defined as re-use for all time. A circular material can be in circulation, but its quality can be reduced from one cycle to the next. So, circularity does not have to be measured by the number of re-use/reuse and recycle loops. It should also contain the remaining useful life of the material.

The proposed PLI framework can be used to categorize the appropriateness of a PET material for reusing, mechanical recycling, low-value recovery, or downcycling. This is helpful for circular product design, route selection for the recycling system and material quality decisions.

4.4. Dataset Limitations

A limitation of the study is that the data is secondary. The values were obtained from various studies under different experimental conditions, materials, sample preparation, processing temperatures, ageing environments and test protocols. Thus, the entropy and energy variables are not measured but rather proxies.

Another restriction is the lack of processing time, residence time, hysteresis loop area and exact values of energy dissipation in many papers. For the sake of not overstating the results, records that did not have adequate quantitative variables were kept in the record for the sake of traceability, but not used in strong weighted PLI interpretation. Although there are some restrictions, the framework proved to be of value as it offers a transparent, repeatable and extendable approach to modelling the recycled PET lifespan from peer-reviewed literature.

4.5. Future Work

Future work should involve enlarging the data-set by obtaining further numerical data from plots and tables. Research papers on residence time, extrusion temperature, fatigue hysteresis, DSC/TGA parameters, intrinsic viscosity, molecular weight and retained mechanical properties should be given priority. The model may also be optimized by running tests with various weighting factors for the damage index and comparing the predictions of the PLI with the failure or rejection threshold for the material during recycling.

5. Conclusion

A thermodynamics lifespan modelling framework for recycled PET under circular use scenarios was developed in the scope of this study based on literature research. Constructed dataset created using peer-reviewed PET recycling, fatigue, ageing and degradation studies. These data were then transformed into entropy-generation proxies, energy-dissipation proxies, cumulative entropy endpoints, damage index values and a PET Lifespan Index.

The preliminary findings show that circular PET use is not thermodynamically neutral. Reuse and recycling extend material utility, but each circular-use stage introduces irreversible degradation. Fatigue cycling, thermal ageing, processing history, intrinsic viscosity loss, crystallinity change, and strength reduction all contribute to lifespan consumption.

The full dataset-level classification identified 31 reuse or high-grade recycling records, 13 mechanical recycling records, 16 downcycling records, 11 end-of-life or low-value recovery records, and 12 limited-information records retained for traceability. The weighted entropy/proxy subset classified 24 records as reuse or high-grade recycling, 38 as mechanical recycling, and 2 as downcycling. These results indicate that PET circularity must be evaluated using both environmental and material-performance criteria.

The proposed PET Lifespan Index provides a practical tool for connecting thermodynamic degradation proxies to circular-use decisions. It can be refined as more peer-reviewed data are extracted and may serve as a foundation for journal-level research on polymer lifespan modelling under circular economy conditions.

Funding

This research received no external funding.

Author Contributions

A.O.U. conceived the study, conducted the literature review, curated the dataset, developed the modelling framework, performed the analyses, and drafted the manuscript.

M.A.O. contributed to conceptualization, methodology development, supervision, and critical revision of the manuscript.

I.L. contributed to manuscript review and editing, interpretation of results, supervision, project coordination, and serves as the corresponding author. All authors read, reviewed, revised, and approved the final manuscript.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Eboh, F. C., Osideko, O. O., and Onitiri, M. A. Fabrication of extrude filament from waste polyethylene terephthalate (PET) plastics for 3D printers. *FUOYE Journal of Engineering and Technology*, 6, 77–82, 2021. <https://doi.org/10.46792/fuoyejet.v6i2.636>
- [2] Ogunsakin, A. M., and Onitiri, M. A. Recycling PET bottles for additive manufacturing: A method for 3D printer filament production. *Nigerian Journal of Technology*, 43, 676–684, 2024. <https://doi.org/10.4314/njt.v43i4.8>
- [3] Onitiri, M. A. Assessing production temperature as it affects the tensile properties of polyethylene terephthalate. *West Indies Journal of Engineering*, 47, 72–77, 2024. <https://doi.org/10.47412/LDCX2551>
- [4] Onitiri, M. A., and Adeniyi, J. S. O. Effects of temperature on the tensile properties of extruded virgin and recycled unplasticized polyvinylchloride (UPVC) plastics. *Nigerian Journal of Technological Development*, 3, 80–87, 2003.
- [5] Geyer, R., Jambeck, J. R., and Law, K. L. Production, use, and fate of all plastics ever made. *Science Advances*, 3, e1700782, 2017. <https://doi.org/10.1126/sciadv.1700782>
- [6] Onitiri, M. A. Service-Life Stewardship: A Thermodynamic and Socio-Technical Systems Engineering Framework for Circular Manufacturing in High-Entropy Industrial Environments. *Circular Economy and Sustainability*, Under review, 2026.

- [7] Onitiri, M. A., and Ugboaga, A. O. Thermodynamic Lifespan Modelling of Recycled PET under Circular Use Scenarios: An Integrated Thermodynamic Modelling Framework. *Express Polymer Letters*, In preparation, 2026.
- [8] Gomes, S., Pimentel, A., Monteiro, M. J., Marinho, A., and Melo, A. Thermal and chemical characterisation of reprocessed PET: A study on commercial, recycled, bottle-grade and textile blend. *Materials*, 18, 4394, 2025. <https://doi.org/10.3390/ma18184394>
- [9] Ronkay, F., Slezák, E., Gere, D., Lukács, N., Gyalai-Korpos, M., Molnár, A. D., and Bocz, K. Thermoanalytical approach to assess riverine PET litter and its recycling potential. *Scientific Reports*, 15, 15673, 2025. <https://doi.org/10.1038/s41598-025-94925-y>
- [10] Santomasi, G., Todaro, F., Petrella, A., Notarnicola, M., and Thoden van Velzen, E. U. Mechanical recycling of PET multi-layer post-consumer packaging: Effects of impurity content. *Recycling*, 9, 93, 2024. <https://doi.org/10.3390/recycling9050093>
- [11] Pinter, E., Welle, F., Mayrhofer, E., Pechhacker, A., Motloch, L., Lahme, V., Grant, A., and Tacker, M. Circularity study on PET bottle-to-bottle recycling. *Sustainability*, 13, 7370, 2021. <https://doi.org/10.3390/su13137370>
- [12] Teles, B. A. de S., Belli, M. C., Barbosa Júnior, I. B., Mancini, S. D., and Kulay, L. Environmental, technical, and circular assessment of the integration of additive manufacturing and open-loop recycling of PET. *Sustainability*, 17, 10068, 2025. <https://doi.org/10.3390/su172210068>
- [13] Korycki, A., Garnier, C., Irusta, S., and Chabert, F. Evaluation of fatigue life of recycled opaque PET from household milk bottle wastes. *Polymers*, 14, 3466, 2022. <https://doi.org/10.3390/polym14173466>
- [14] Panowicz, R., Konarzewski, M., Durejko, T., Szala, M., Łazińska, M., Czerwińska, M., Prasula, P., and Rejmer, W. Properties of polyethylene terephthalate after thermo-oxidative aging. *Materials*, 14, 3833, 2021. <https://doi.org/10.3390/ma14143833>