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# Thermal Insulation, Lasting Consequences: Forecasting ETICS Waste and Its Sustainability Challenges

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# Thermal Insulation, Lasting Consequences: Forecasting ETICS Waste and Its Sustainability Challenges

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**Abstract:** This study quantifies post-demolition External Thermal Insulation Composite Systems (ETICS), with a focus on Expanded Polystyrene (EPS) as insulation material in Germany. Using a top-down approach, it estimates mass distribution at the NUTS-3 level and predicts future EPS waste volumes. Residential and non-residential buildings are categorized by type and construction age, with insulation rates determined through database queries. Waste projections incorporate ETICS lifetimes survey data, and probabilistic single-house sampling. Findings indicate a fourfold increase in annual EPS waste from ETICS by 2050, with 80% originating from residential buildings and 20% from non-residential structures, predominantly in urban areas. ETICS pose recycling challenges due to their composite nature, combining organic and inorganic materials, and the presence of HBCD, a toxic flame retardant banned by the EU in 2015. Currently, most ETICS waste is incinerated, a linear approach that fails to address the anticipated surge in waste volumes. Given these projections, sustainable alternatives for ETICS waste management are urgently needed. The study provides insights into waste distribution across building types and administrative regions, offering a basis for informed policy decisions. The building typology used in this approach is available for other European countries, supporting the development of comprehensive waste management strategies across Europe.

## 1. INTRODUCTION

External thermal insulation dates back to the late 1950s, with the first External Thermal Insulation Composite System (ETICS) installed on a residential building in Berlin. Widespread adoption followed in the 1970s after the global energy crisis, which drove up energy costs and increased interest in building energy efficiency (Michalak, 2021). In response, many countries implemented thermal insulation regulations for residential (RBs) and non-residential buildings (NRBs), with Germany introducing the first of such standards, the "Wärmeschutzverordnung", in 1977. ETICS comprise several layers applied to exterior walls, including adhesive, insulation materials like Expanded Polystyrene (EPS) or mineral wool, dowels, a fiberglass mesh, and protective coatings. As of 2022, around 1.35 billion $m^2$ of ETICS had been installed in Germany, with EPS making up ~80% of the insulated stock (Schwitalla et al., 2023). EPS has a high thermal efficiency, low weight, affordability, moisture resistance, and a relatively low environmental footprint (Densley Tingley et al., 2015; Yucel et al., 2003). However, the end-of-life (EoL) management of EPS-based ETICS remains a critical challenge. Key issues include contamination with hexabromocyclododecane (HBCD), a flame retardant with restricted use, and prevailing deconstruction practices that result in mixed and unsorted construction waste (Heller & Flamme, 2020). Given that large-scale ETICS installations began in the 1970s and their estimated lifespan of 40 to 60 years (Albrecht & Schwitalla, 2015), significant volumes of EPS waste are expected to emerge in the coming decades. Currently, municipal solid waste incineration (MSWI) is the dominant disposal method for EPS waste. However, this approach is highly linear in its resource utilization, running counter to the EU's circular economy strategy (European Commission, 2015). Additionally, MSWI facilities already operate near maximum capacity (Heller & Flamme, 2020), and the high calorific value of EPS presents further technical and economic challenges (Lützau et al., 2024; Mark et al., 2015). Projections indicate that EPS waste volumes from ETICS will double by 2030 and triple by 2050 compared to 2020 levels (Albrecht & Schwitalla, 2015; Heller, 2022) or even quadruple until 2050 (Bischof et al., 2025). Some estimates suggest an even greater increase, with waste volumes potentially rising tenfold between 2020 and 2040 (Schleier et al., 2022). To treat these rising masses, several recycling pathways beyond incineration have been explored. These include chemical recycling (e.g., pyrolysis), solvent-based physico-chemical recycling like the "PolyStyreneLoop" process, mechanical recycling, and co-processing in cement plants (Heller & Flamme, 2020). Their successful implementation depends on reliable EPS waste generation, localization, and temporal distribution data, which are essential for designing efficient recovery and recycling systems. Despite the growing importance of EPS waste management, comprehensive data on ETICS waste remains scarce. A major limitation is the reliance on aggregated waste statistics, which often do not distinguish ETICS from other types of construction waste. Some studies refine these estimates by incorporating ETICS installation data, categorized by insulation material type (Schleier et al., 2022; Schwitalla et al., 2023). However, these approaches mostly lack the necessary spatial resolution, required for designing sustainable reverse logistics networks, as they rely on aggregated national or coarse regional statistics. Earlier waste generation assessments frequently focus on RBs because underlying statistical data (such as housing censuses or insulation rate surveys) primarily cover this sector. NRBs are underrepresented due to the heterogeneity of use types, construction methods, and lack of standardized reporting for insulation systems in the non-residential sector. Previous top down ETICS quantity assessments for Germany are based on Albrecht & Schwitalla (2015) and are therefore based on old data, leveraging ETICS installation statistics until 2012. So, there is a clear research gap in estimating ETICS waste generation, as well as in localized and temporally resolved assessments for both *RBs* and *NRBs*, leveraging the latest available industry data. This study presents a novel top-down methodology for quantifying EPS waste from ETICS. The approach (Section 2) is followed by the results (Section 3), and a discussion of key implications (Section 4).

## 2. METHODS

The presented approach constitutes a top-down methodology for allocating the installed volume of ETICS, particularly those based on expanded polystyrene (EPS), installed in Germany. In the subsequent step, the point in time at which the installed ETICS masses become waste is calculated. The outcome provides a breakdown of the anticipated annual mass flows, as well as their spatial distribution across all 401 German administrative districts. The approach is structured in three parts: a) Data collection & pre-processing, b) Data processing and Allocation, c) Sampling and forecasting (Figure 1)

### 2.1 Data Collection & Pre-processing

#### 2.1.1 ETICS installation statistics

In a first step, information on the total installed amount of ETICS in Germany between 1969 and 2022 was collected from the German association of thermal insulation composite systems (FVWDVS) and its successor, the association for insulation systems render and mortar (VDPM).

#### 2.1.2 Building stock data

German building data stock is compiled from official sources. For *RBs*, the primary dataset is the German Census of 2011 and its updates until 2022, provided by the German Federal Statistical Office. Its classification follows the German *RB* typology in accordance with TABULA typology (Loga et al., 2015). This typology differentiates *RBs* into four main categories: single-family houses (*SFH*), terraced houses (*TH*), multi-family houses (*MFH*), and large multi-family houses (*LMH*). Furthermore, the classification includes twelve construction age classes (*cac*). Each building

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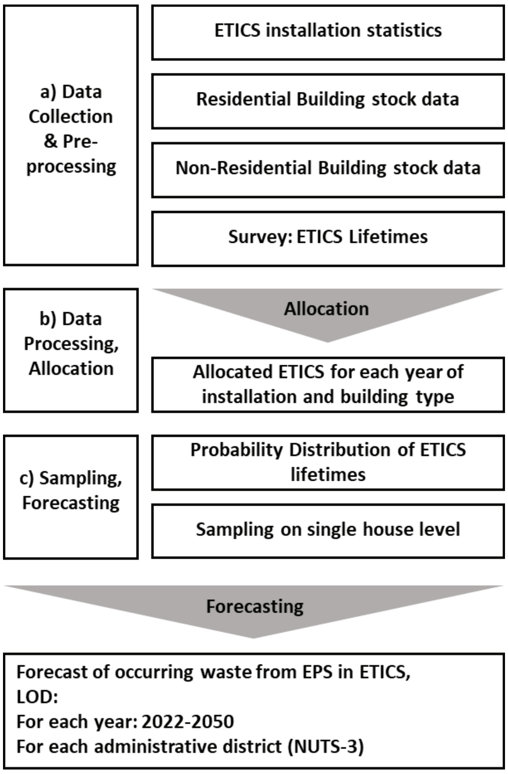



*Figure 1: Methodological Approach*

archetype is associated with standardized values for characteristics such as energy consumption, heating systems, and external wall surface area exposed to air, excluding windows and doors. In the developed top-down methodology, selected building types are analyzed based on this classification. The building data from the German Census is mapped to this classification based on the construction period, the number of housing units per building, and whether the buildings are detached or terraced. Beyond *RBs*, *NRBs* are also considered in this approach, specifically those subject to the German Energy Transition in Buildings Act, which mandates compliance with thermal insulation regulations. The classification of *NRBs* follows (Hörner & Bischof, 2022). While their age distribution is obtained from (Hörner, 2021). To achieve spatial distribution at NUTS-3 level, construction completion statistics from the German Federal Statistical Office are used to allocate *NRBs* across Germany's 401 administrative districts. Since the most extensive dataset covers construction completions from 1995 to 2022, earlier figures (1969–1994) are estimated using linear trend continuation. District boundaries adjustments since 1995 are made using official territorial revision records and personal phone conversations with the respective state authorities. To enhance allocation accuracy, data on insulation progress across different building categories is incorporated. Insulation rates for *RBs* are sourced from the Datenerhebung Wohngebäudebestand 2016 (Cischinsky & Diefenbach, 2018), entailing data from approximately 17,000 buildings through surveys. For *NRBs*, insulation data is obtained from the Forschungsdatenbank Nichtwohngebäude (Hörner, 2022), a research database compiled from energy performance surveys conducted between 2015 and 2019. Queries were performed using "R-Statistics" to extract relevant subsets of the data, allowing for the assessment of insulation progress across different building types. This enables a precise allocation of insulation volumes based on the insulated external wall surface area, a key criterion for the allocation process, improving the allocation accuracy compared to previous methodologies.

### 2.1.3 Survey: ETICS lifetimes

The service life of ETICS is a key determinant in forecasting waste generation, as it directly impacts the timing of waste accumulation. However, estimates vary significantly in the literature, ranging from 21 years (Tavares et al., 2020) to 65 years (Lindner et al., 2020). To address this uncertainty, a survey was carried out to obtain expert assessments on the lifespan of EPS-based ETICS. The survey participants consist of a range of professionals, including architects, engineers, government representatives, ETICS manufacturers, plasterers, and academic researchers. Respondents were asked to estimate the lifespan by providing minimum, maximum, and most likely values based on their experience. Out of the 75 total responses, 64 provided their "most likely" estimate, while 40 specified the minimum and 42 the maximum lifespan. The results revealed an average lifespan of 40 years for EPS-based ETICS, with minimum and maximum estimates averaging 25 and 55 years, respectively. Survey stakeholder groups were chosen as to minimize potential biases, however as all

2.2 Data Processing, Sampling and Forecasting

In this section, we outline the methodology employed for the processing of building stock data, the allocation of insulation volumes, and the forecasting of waste generation based on the calculated lifespans. The workflow consists of three key steps: calculating the insulated external wall surface, allocating the mass of thermal insulation to the corresponding wall area, and forecasting the year of waste generation for each building.

**Calculation of Insulated External Wall Surface Area**

For each RB and NRB archetype - single-family houses (SFH), terraced houses (TH), multi-family houses (MFH), large multi-family houses (LMH), production buildings (PB) and service buildings (SB) - the insulated external wall surface area (WSA) is computed. The formula used is as follows:

$$\text{Insulated WSA}_{bt,\,year,\,ad} = \text{external wall surface area}_{bt,\,cac} * \text{insulation rate}_{bt,\,cac} * \text{nr. of constructed buildings}_{bt,\,year,\,ad}$$

*with*

$bt \in \{\mathrm{SFH, TH, MFH, LMH, PB, SB}\}$

$year \in \{1969, 1970, \dots, 2022\}$

$ad \in \{1,2, \dots, 401\}$

$$cac \in \begin{Bmatrix} 1969-1978, 1979-1983, 1984-1994, 1995-2001, 2002-2009, \\ 2010-2022 \end{Bmatrix}$$

It calculates the total insulated external wall surface area for each year, building type, and administrative district considering the specific insulation rates for each category. The resulting value is a crucial input for the subsequent allocation of insulation mass and waste forecasting.

**Allocation of Thermal Insulation Mass**

Next, the mass of EPS from ETICS is allocated to the insulated external wall surface area for each year, building type and administrative district. It is based on the principle that the thermal insulation mass correlates directly with the area of the wall insulated. By allocating the total installed insulation mass of each year to the calculated insulated *WSA*, the mass of insulation that will eventually be discarded when reaching the end of its service life can be estimated.

**Forecasting Waste Generation: Lifetime and Year of Waste Accumulation**

Finally, the year of waste generation for each building is forecasted, based on the estimated lifespan of the insulation systems. The procedure is as follows for each building:

**a) Sampling the Building Lifespan:** For each building, a lifespan is randomly sampled from a triangular distribution that represents the expected lifespan of EPS-based ETICS, based on expert survey data. This distribution accounts for minimum, maximum, and most likely lifespan estimates, allowing for a range of possible outcomes.

**b) Calculating the Year of Waste Generation:** The sampled lifespan is then added to the year of construction for each building. The resulting value is rounded to the nearest integer to determine the year in which the building's thermal insulation is expected to be replaced or removed, i.e., the year of waste generation for the associated insulation mass.

**c) Allocating Waste Generation by year and administrative district:** This process is repeated for all buildings in each administrative district ensuring that waste generation is distributed across both time (year) and geography (administrative district). This method allows for a detailed and accurate forecast of insulation waste generation, enabling better planning for recycling and disposal activities in the context of the building stock's lifespan.

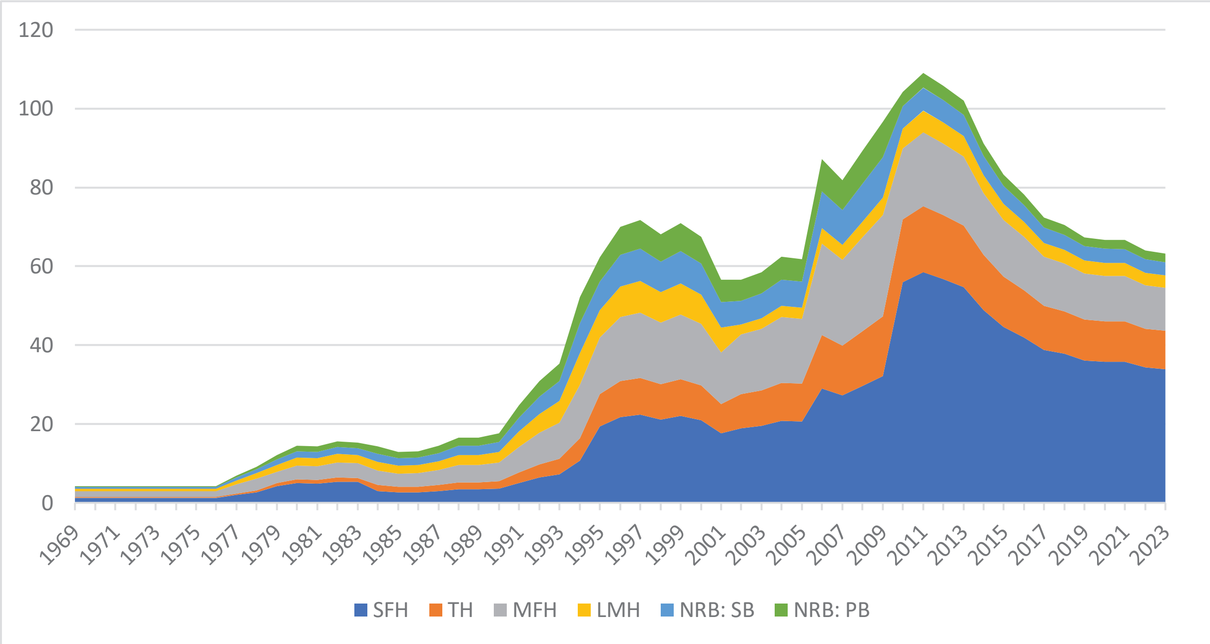
## 3. RESULTS

### 3.1 ETICS installations between 1969 and 2022 and their distribution across the German building stock

The presented top-down approach provides insight into the distribution of insulation masses across building classes, i.e. *RBs* and *NRBs*, as well as building types SFH, TH, MFH, LMH, PB, and SB. Of the total 2.58 Mt of EPS insulation material, 84% is allocated to *RBs* and 16% to *NRBs*. Regarding building types, the following distribution can be observed: SFH (41%), TH (14%), MFH (22%), LMH (7%), SB

(9%), PB (7%). The time progression of installed EPS insulation mass for ETICS for the different building types can be seen in Figure 2.

Figure 2: Time progression of installed EPS insulation mass [kt] for all building types (bt) from 1969 to 2023




### 3.2 Prediction of future EPS waste from ETICS

Based on the ETICS installation statistic provided by the VDPM (Schwitalla et al., 2023) future projections of EPS waste from ETICS were derived by sampling lifespans on the single building level for each year and administrative district individually. The resulting projection extends over a span of 30 years into the future (until 2055). A 30-year period was chosen as it lies significantly below the expected lifespan of ETICS of 40 years. This allows for avoiding assumptions about future quantities of installed EPS-based ETICS. The projected waste generation for Germany as a whole (Figure 3) shows that we are currently observing the initial stages of an upward trend. The annual waste volumes are expected to quadruple compared to current levels, reaching a plateau of approximately 80 kt of EPS insulation around 2050 with cumulative EPS waste from ETICS of over 2000 kt in 2055. This will inevitably lead to further exacerbation of the current waste disposal issue for EPS from

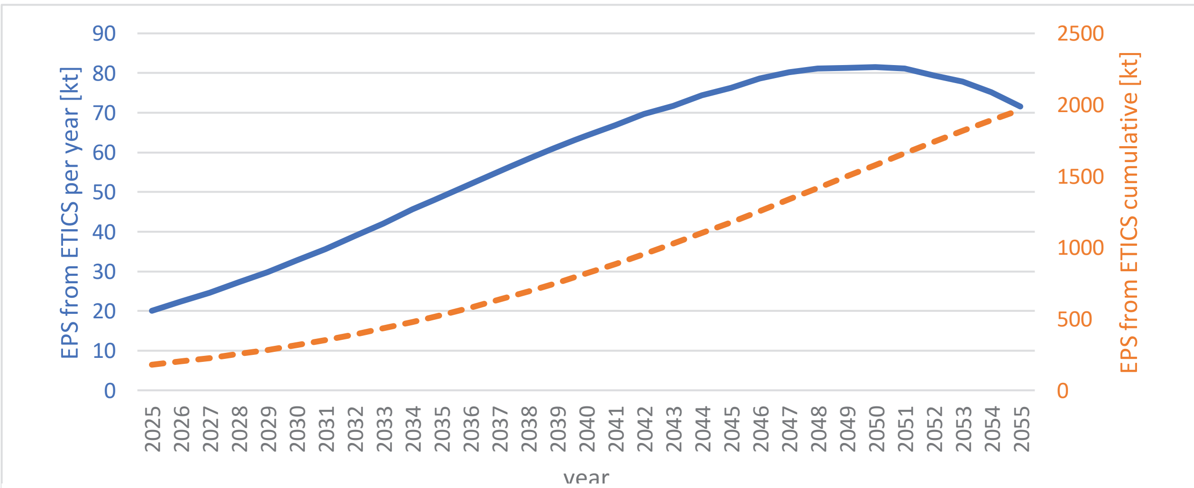



*Figure 3: Anticipated EPS from ETICS waste*

ETICS. The decrease in annual waste quantities following the plateau in 2050 is partly attributable to the declining market share of EPS within the ETICS market observed over recent years (Schwitalla et al., 2023). This decline is further compounded by the fact that many ETICS installations from previous years are nearing the end of their useful life around 2050. It should be explicitly noted that the presented figures solely pertain to the mass of the EPS insulation layer, not the mass of the actual resulting ETICS deconstruction waste. In practice however, contamination of EPS waste from ETICS occurs due to its application in composite systems and demolition practices in the construction industry (Heller & Flamme, 2020). The total mass of ETICS waste can be estimated by utilizing the mass share of EPS in the composite system. However, the mass fraction is influenced by a multitude of factors, such as the type and thickness of the EPS insulation layer, as well as the structure of the surrounding composite system. Accordingly, literature values demonstrate a high variance. Ranging from 8.85% (Michalak, 2021)  up to 19.20% reported by VDPM (Verband für Dämmsysteme, Putz und Mörtel e.V., 2017). Applying these mass shares, the resulting cumulated total ETICS deconstruction waste mass occurring between 2025 and 2055 ranges between 9.4 Mt and 20.4 Mt, with maximum annual ETICS deconstruction waste generation of 424 kt to 921 kt for 2050. In addition to the aggregated results, the presented study allows for inferences regarding the spatial distribution of installed ETICS masses. Consequently, the prediction of resulting cumulative waste masses at the NUTS3 level of detail is feasible. These outcomes are visualized in the form of heat maps (Figure 4) where darker districts have a higher expected cumulated EPS from ETICS waste. The maps clearly show that accumulated EPS masses from ETICS concentrate in the large metropolitan regions like Berlin, Hamburg, Munich and the Hannover region. Additionally, an increased concentration can be observed for North Rhine-Westphalia, Western Lower Saxony and the Upper Rhine and Neckar region.

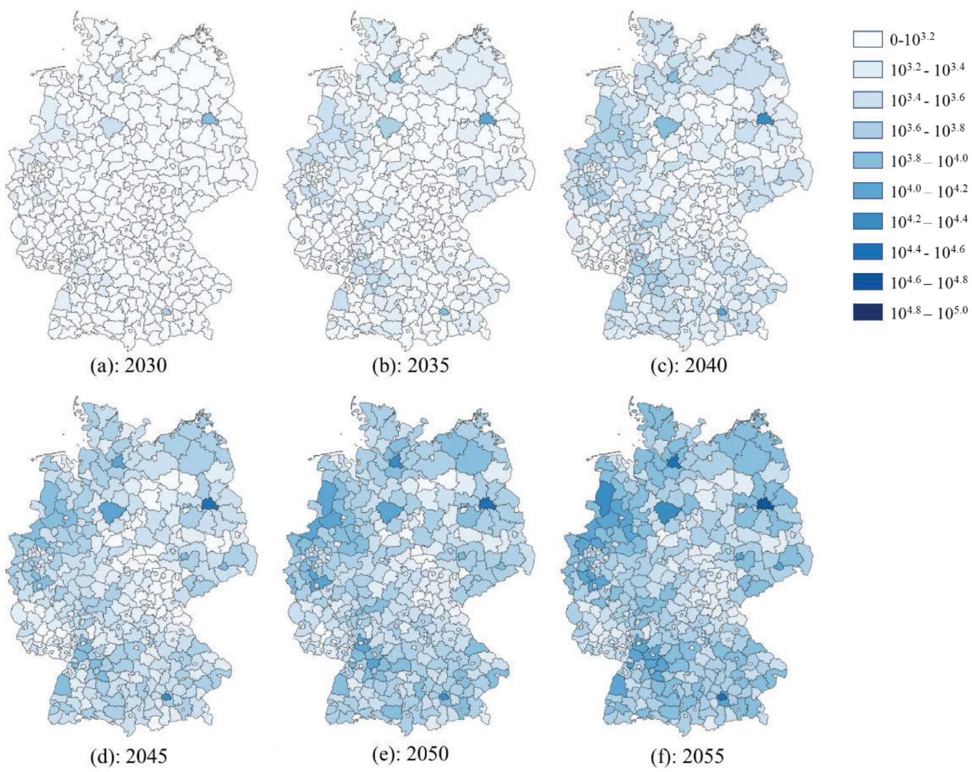



*Figure 4: Projected cumulative EPS from ETICS waste mass [t] in the years (a) 2030, (b) 2035, (c) 2040, (d) 2045, (e) 2050 and (f) 2055.*

## 4. DISCUSSION

The results are broadly consistent with existing literature on ETICS quantity estimation, supporting the validity of the proposed approach. A key advantage lies in the integration of recent production data (Schwitalla et al., 2023) and high-resolution allocation of ETICS waste based on external wall surface area and insulation progress. This enables temporally and spatially granular analysis at the district level, aiding efficient recycling network design. Unlike earlier studies that often exclude *NRBs*, this method considers four residential and two NRB types, improving allocation accuracy. Incorporating stakeholder survey data from industry and academia further strengthens lifetime assumptions, though results may have limited transferability outside Germany due to regional specificity. The method's adaptability, supported by a harmonized building typology available in other European countries (e.g., Spain), enables cross-country comparisons and supports EU-wide recycling strategies. Nonetheless, some limitations remain: assuming insulation coincides with construction year may affect time accuracy; use of industry data may introduce bias; and limited NRB stock data at the NUTS-3 level required extrapolation, potentially reducing spatial precision.

## 5. CONCLUSION

This study presents a novel methodology for estimating ETICS waste masses, leveraging the latest industry data, a comprehensive building typology, and high spatial and temporal granularity. By incorporating both *RBs* and *NRBs* and employing probabilistic lifetime sampling, the approach enhances the accuracy and applicability of waste mass predictions. Furthermore, its adaptability to other European contexts underscores its potential for broader application. Assumptions regarding insulation timing, potential industry bias, data gaps for non-residential buildings, and the geographic scope of stakeholder input highlight areas for future improvement. Current limitations could be met through enhanced data collection, validation in different climatic regions, and cross-country comparative studies. Projections show that annual EPS waste from ETICS will quadruple by 2050, reaching about 80 kt/year, with cumulative waste exceeding 2,000 kt by 2055. Waste is concentrated in major urban areas, highlighting the need for targeted management strategies. Solvent-based recycling offers a promising alternative to energy recovery for EPS waste from ETICS. A process developed by Fraunhofer enables both polystyrene recovery and removal of HBCD contaminants (Demacsek et al., 2019), with demonstrated environmental and economic benefits (Schleier & Walther, 2024; TÜV Rheinland LGA Products GmbH, Germany, 2019). A pilot plant in Terneuzen (NL) is operational, but its 3,000-tonne annual capacity covers less than 4% of projected peak waste, underscoring the need for broader infrastructure to scale this approach. Overall, the findings provide a valuable foundation for optimizing ETICS waste management and recycling strategies, contributing to sustainable construction practices. By offering a replicable and adaptable framework, this research supports informed decision-making for policymakers, industry stakeholders, and researchers to advance circular economy initiatives in the built environment.

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