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# Designing a new recycling network for post-demolition autoclaved aerated concrete (AAC) in Europe

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# Designing a new recycling network for post-demolition autoclaved aerated concrete (AAC) in Europe

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**Abstract**. Autoclaved aerated concrete (AAC) is a widely used building material for masonry blocks. Its porous structure and mineral composition lead to low thermal conductivity and fire resistance. European AAC production and usage strongly increased in the 1960s and 1970s. Therefore, assuming limited buildings' lifetimes, significant post-demolition AAC volumes can be expected in the following decades. However, post-demolition AAC recycling in high-value environmentally friendly applications is still to be established as most post-demolition AAC is currently landfilled. Different recycling options for post-demolition AAC are presently being researched. However, a recycling network to implement these options is neither designed nor established. This contribution focuses on creating a European recycling network, including mathematical modelling, data acquisition, and solving the model. i.e. minimising the total costs. The mathematical modelling uses a capacitated warehouse location problem with multi-sourcing and direct delivery. Results show that recycling plants of smaller capacity (100,000 t input/a) are placed in the recycling networks in 2020 and 2025. With higher waste quantities being expected from 2030 onwards, plants with a larger capacity (200,000 t input/a) are added, especially in Poland, where the highest pd-AAC amount in Europe is expected. The recycling network shows a decentralised structure with numerous recycling plants to keep transport costs low. Most network costs result from variable processing costs, showing the highest cost increases from 2020 to 2050. Fixed costs increase with the higher number of recycling plants and account for the second-largest share of total network costs. Transport costs are comparatively low thanks to the decentralised structure of the network. Overall, waste generation is expected to increase by 226% from 2020 to 2050, while the total costs of the recycling network are expected to rise by 151% only. The results support decision-makers in fostering recycling and implementing a circular economy for post-demolition AAC.

Keywords: Autoclaved aerated concrete, post-demolition recycling options, recycling network, location planning, warehouse location problem, circular economy

## 1. Introduction and literature

The construction of buildings uses large amounts of primary resources and causes substantial greenhouse gas (GHG) emissions. Therefore, it is crucial to find significant saving potentials in the construction section to tackle climate change and reach the UN sustainable development goals, including "sustainable cities", "responsible consumption and production", and "climate action" [1]. Recycling demolition waste is an option moving more and more into the focus to reduce primary resource consumption, GHG emissions, and other environmental impacts. Generally, many building materials are recycled (or at least downcycled) today to meet the 70% recycling rate required by the European waste and recycling regulation [2]. However, there is still much recycling potential as some materials, like autoclaved aerated concrete (AAC), are still mainly landfilled. AAC is a widespread building material used to construct one and two-family houses. AAC's popularity is due to its excellent thermal insulation property, high fire resistance, and fast/low-cost construction process. These characteristics result from a low density reaching 300 kg/m³ because of numerous tiny pores formed in the production process. The main inputs for AAC production are sand, cement, quicklime, anhydrite, and water. Small amounts of aluminium added to the suspension start a chemical reaction that produces hydrogen leading to the porous structure. Currently, the global production capacity for non-reinforced AAC blocks is around 450 million m³ [3], and the European AAC production exceeds 16 million m³ annually [4]. Currently, post-demolition AAC (pd-AAC) amounts are enormously increasing. In Germany, around 1.2 million m³ were calculated for 2020, while more than 4 million m³ annually are expected until 2050 [5, 6]. In Europe (including Russia), calculations show pd-AAC amounts of approximately 12.3 million m³ in 2020, potentially reaching 40 million m³ annually by 2050 [7].

Usual recycling options for demolished construction materials include road construction, earthworks, and aggregate in concrete production [8]. However, AAC from the demolition of buildings has less compressive strength than other mineral construction materials and contains sulphate since small amounts of gypsum or anhydrite are used for AAC production. Thus, the standard recycling options for mineral construction and demolition waste are eliminated. New recycling options for pd-AAC are required to avoid landfilling. Some literature studies investigate new possibilities for closed-loop recycling, meaning pd-AAC is used in producing new AAC [9–12]. Others focus on open-loop recycling where pd-AAC is used in the light mortar [13], lightweight aggregate concrete [13, 14], floor screed [15], and shuttering block production [14]. Additionally, the production of belite binders from pd-AAC is investigated [16], which can be used as a substitute for Portland cement and could handle impurities better than other recycling options. A comparison of closed-loop and open-loop recycling options regarding environmental aspects [17, 18] shows that AAC recycling is highly beneficial. However, a precise economic assessment requires modelling and design of an optimised recycling network to investigate minimum transport distances, optimal capacities and the number of factories needed at minimum total cost. Therefore, this study models and plans a new European recycling network for pd-AAC.

Modelling networks is an intensively studied research area. The warehouse location problem (WLP) is a basic model used for various purposes, including the modelling of reverse logistics/recycling networks. Research on the modelling of reverse logistics and recycling networks focuses on a broad selection of materials and case studies, for example, sand [19, 20], demolition waste [21–23], vehicles [24, 25]. carpets [26, 27], paper [28], and plastics [29, 30]. [31] give an overview of the literature on reverse logistics network modelling until 2014. However, specific investigations of the reverse logistics and recycling of pd-AAC is still missing and should be investigated.

## 2. Methodology and materials

### *2.1. Mathematical formulation*

This study designs and models a new recycling network for pd-AAC as a mixed-integer problem (MIP) following the WLP formulation. The mathematical model aims at minimising total cost by placing recycling facilities at the best locations in a static and deterministic way. Moreover, capacity restrictions of the facilities have to be satisfied. Thus, the model is a capacitated reverse logistics model. Essential characteristics of the model are multi-sourcing, meaning that different sources deliver the material to the recycling facility and direct delivery without interaction between recycling facilities. Furthermore, recycling plants of two different capacities can be placed. The model's sets, decision variables, and parameters are given in Table 1.

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**Table 1.** Sets, decision variables, and parameters used for the AAC recycling network modelling.

| | |
|---|---|
| *Sets* | |
| $S$ | set of all possible pd-AAC supply locations |
| $R$ | set of all possible recycling plant locations |
| *Decision variables* | |
| $x_{sr}$ | quantity shipped from supply location $s\epsilon S$ to recycling plant $r\epsilon R$ |
| $q_s^{disposal}$ | quantity disposed at supply location $s\epsilon S$ |
| $y_r$ | indicator variable for large recycling plant status at location $r\epsilon R$ (1=open, 0=closed) |
| $z_r$ | indicator variable for small recycling plant status at location $r\epsilon R$ (1=open, 0=closed) |
| *Parameters* | |
| $c^{shipment}$ | shipment costs |
| $c_r^{recycling,variable}$ | variable costs of pd-AAC treatment at the recycling plant at location $r\epsilon R$ |
| $c_r^{recycling,fixed,large}$ | fixed costs of operating a large recycling plant at location $r\epsilon R$ |
| $c_r^{recycling,fixed,small}$ | fixed costs of operating a small recycling plant at location $r\epsilon R$ |
| $c_s^{disposal}$ | costs for disposing pd-AAC at supply location $s\epsilon S$ |
| $K_{large}$ | maximum input capacity of the large recycling plants |
| $K_{small}$ | maximum input capacity of the small recycling plants |
| $q_s^{supply}$ | pd-AAC quantity supplied in supply location $s\epsilon S$ |
| $l$ | maximum share of the quantity disposed in relation to the quantity supplied |

The set $S$ contains all locations where pd-AAC emerges, while $R$ contains all possible sites for recycling plants. Further information on the input data is given in section 2.2. The decision variables include the flow variable ($x_{sr}$), indicating the amount transported between the supply and the chosen recycling locations. Furthermore, the variable determining the quantity of pd-AAC disposed of per supply location ($q_s^{disposal}$) and indicator variables for the status (open or closed) of a possible large or small recycling plant ($y_r, z_r$) are part of the decision variables. The costs for shipment, variable and fixed recycling costs, and disposal costs are parameters of the model. Besides, the maximum capacity of a large or small recycling plant is defined by $K_{large}$ and $K_{small}$. Finally, the quantity of pd-AAC (supply) and the maximum share that is allowed to be disposed of are part of the parameters. The cost-minimising MIP is given through equations (1) to (7).

$$\begin{aligned} min \quad & \sum_{s\in S}\sum_{r\in R} x_{sr} \cdot c^{shipment} + \sum_{r\in R} c_r^{recycling,variable}\left(\sum_{s\in S} x_{sr}\right) \\ & + \sum_{r\in R} c_r^{recycling,fixed,large} \cdot y_r + \sum_{r\in R} c_r^{recycling,fixed,small} \cdot z_r \\ & + \sum_{s\in S} q_s^{disposal} \cdot c_s^{disposal} \end{aligned} \tag{1}$$

$$s.t. \quad \sum_{r\in R} x_{sr} + q_s^{disposal} = q_s^{supply} \qquad \forall s \in S \tag{2}$$

$$\sum_{s\in S} q_s^{disposal} \leq l \cdot \sum_{s\in S} q_s^{supply} \tag{3}$$

$$\sum_{s\in S} x_{sr} \leq K_{large} \cdot y_r + K_{small} \cdot z_r \qquad \forall r \in R \tag{4}$$

$$y_r + z_r \leq 1 \qquad \forall r \in R \tag{5}$$

$$x_{sr}, x_{rd}, q_s^{disposal} \geq 0 \qquad \forall s \in S, \forall r \in R, \forall d \in D \tag{6}$$

$$y_r, z_r \in \{0,1\} \qquad \forall r \in R \tag{7}$$

The MIP minimises the total costs described by the objective function given in equation (1). It includes transport costs, variable recycling costs, fixed costs of the recycling plants, and disposal costs. The objective function is subject to six constraints, given in equations (2)-(7). The model's first constraint, specified by equation (2). demands that all pd-AAC has to be disposed of or shipped to a recycling plant. Leaving quantities untreated is not permitted. Furthermore, equation (3) states that the total quantity disposed of is limited to a maximum share of the total quantity supplied throughout Europe, following for example legal requirements or climate protection efforts. Besides, pd-AAC can only be shipped to locations where small or large recycling plants are opened, which is clarified through equation (4). This constraint also ensures that the small or large recycling plant's capacity must not be exceeded. Moreover, equation (5) ensures that the number of recycling plants, either small or large, is limited to one at the same time in one region. Finally, equation (6) defines the non-negativity of the transport variables and the quantity disposed of, while equation (7) determines that every recycling plant is restricted to be either open or closed.

### 2.2. *Input data*

In this section, the required input data for the model is given. The supply of pd-AAC is spread over the whole of Europe. However, the model needs discrete supply locations. Therefore, the total pd-AAC volume of a NUTS 2 region is assumed to emerge at the region's centre of gravity. The centres of gravity of all NUTS 2 regions are also considered as possible recycling locations. The material is assumed to be transported exclusively by road transport through the recycling network. Road transport costs vary significantly depending on various factors, including transport material, transport distance, infrastructure/pace, payload, and capacity utilisation. Average transport costs vary between 0.2 €/t*km for short distances (maximum 100 km) and can reach a value slightly lower than 0.1 €/t*km for long distances (above 500 km) [32]. Therefore, we assume constant transport costs of 0.2 €/t*km in this study as the before-mentioned costs are from 2016 and have increased until today. Additionally, transport distances are expected to be shorter than 500 km for the majority of the transports in the network.

Information on variable and fixed recycling costs for AAC recycling is not available as AAC recycling is not established yet. Therefore, assumptions had to be made. The labour costs, electricity/fuel demand, and maintenance costs are expected to be the most influencing aspects of the variable recycling costs. A life cycle assessment of pd-AAC recycling [17] and a study on AAC crushing [33] provides data on energy and fuel demand that is used to approximate electricity and fuel costs of 5 €/t. Furthermore, the recycling process is expected to run on a high level of automation. Thus, ten workers are assumed to be needed for plant operation with 25 t/h throughput (see below). Total labour costs then sum up to 16 €/t assuming costs of 40 €/h worked [34]. Additionally, maintenance has to be considered and especially the crushing process causes some wear on the machine. Overall, costs of 25% of the plant operation, thus, 4€/t are assumed for maintenance and wear, leading to overall variable recycling costs of 25 €/t. It is assumed that the recycling plant's capacity does not influence the variable recycling costs.

However, fixed costs differ. Generally, they depend on the total investment for a recycling plant and its depreciation (for example, 10% annually in case of constant depreciation over ten years) and interest payment (interest rates of 5-10% per year could be expected) which are the most relevant cost drivers. The total investment for a large AAC recycling plant is assumed to be 10 million € as the plant uses established technologies and machines for crushing, air separation, and near-infrared spectroscopy sorting. Annual fixed costs are supposed to be 20% of the total investment and, therefore, sum up to 2 million €. The input capacity depends on the machines used, their throughput, and the operating time of the recycling plant. We assume two plant sizes that can be implemented with a continuous operation of the recycling plant when necessary (up to 8000 h/a when maintenance is considered). Thus, a capacity of 200,000 t/a for the large recycling plant is possible as required machines like crushers, air separators, or vibrating screens usually reach throughputs of 25 t/h and even above. The small recycling plant is assumed to have half of this capacity (100,000 t/a). Fixed costs cannot be considered to halve due to economies of scale. Thus, 1.2 million € annual fixed costs are assumed for a small recycling plant. A more detailed calculation of the variable and fixed costs of pd-AAC recycling is subject to current research.

Disposal costs were obtained for Germany by research in online portals. Prices differ regionally around an average of 100 €/t, including transport. Data for other countries are not available. Therefore, 100 €/t disposal costs are assumed for all regions in Europe. Supply locations are all NUTS 2 regions (their centre of gravity) in Europe (see above). The pd-AAC quantity supplied per region is calculated based on the pd-AAC volumes per European country for 2020, 2025, 2030, 2040, and 2050 [7]. These volumes per country are split into volumes per NUTS 2 region according to the share of a country's population living in this region in 2021 [35]. All EU members, the candidates for membership (in 2021, except Turkey), and the members of the European Free Trade Association (except Iceland) are considered since Eurostat [35] provides population data on NUTS 2 level for these countries. As pd-AAC volume predictions are given until 2050, the future recycling network's evolution is also be investigated. The maximum quantity that can be disposed of is limited to 30% of the total pd-AAC supplied following the European waste and recycling regulation demanding a recycling rate for mineral wastes of 70% [2].

### *2.3. Implementation*
The CPLEX solver, integrated into Python 3.8.5 via the docplex library, was used to solve the model. Maximum computing time was set to 60 seconds on an Intel(R) Core(TM) i5-8265UC CPU @ 1.60GHz, 8 GB RAM machine. Calculations resulted in optimality gaps for all calculated networks below 0.3%.

## 3. Results
For the above-mentioned model parameters, Figure 1 shows the expected pd-AAC volume per NUTS 2 region in metric tons and the optimised recycling network for 2020.

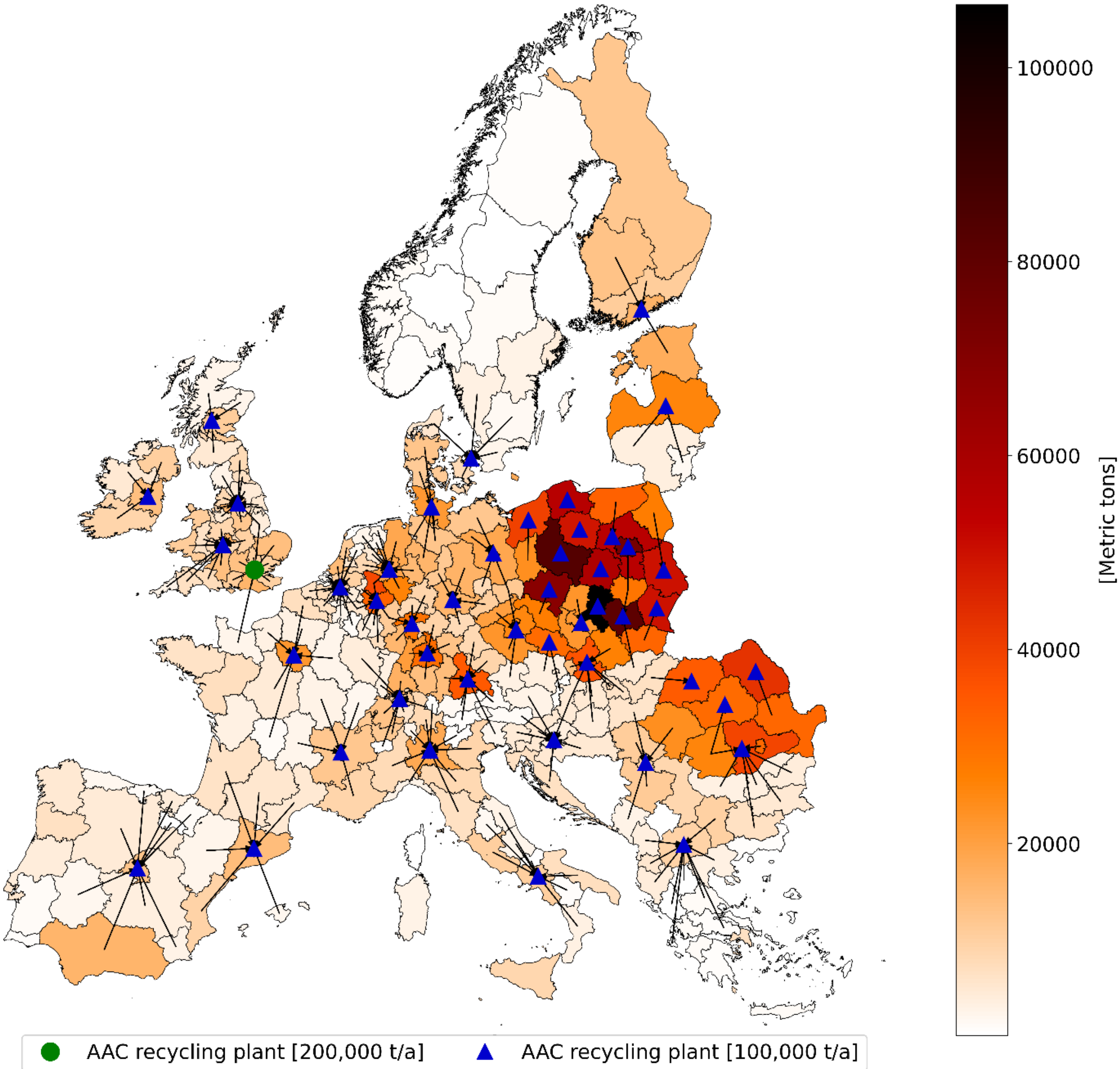


**Figure 1.** Optimised European recycling network for pd-AAC in 2020 including small (blue triangle) and large AAC recycling plants (green circle) as well as transports between NUTS 2 regions (black connection lines). The colouring of the map reflects the pd-AAC amount from low (white/orange) to high (red/black).

There are high regional differences in pd-AAC volumes in Europe. Agglomerations and capital cities with a large population (e.g., London, Paris, and Madrid) show higher pd-AAC amounts than the surrounding regions. Moreover, high volumes are found in the UK, Germany, Poland, the Czech Republic, Slovakia, and Romania. The pd-AAC collection areas of the recycling plants are relatively small, as many small recycling plants are located in these countries. The optimised model favours many small recycling facilities over a few large ones to shorten transportation distances. Countries and regions with lower volumes of pd-AAC, such as Spain, France, Italy, and Southeastern Europe, also have fewer recycling plants in the optimal solution. Here, a small recycling plant processes waste from several regions. As a result, the collection areas increase and can reach up to 400 km.

Key figures for the optimal recycling network for 2020 can be found in Table 2 and Figure 2. The total costs of the recycling network are about 200 M€ and consist of 41% (82 M€) variable processing costs of the pd-AAC waste, 29% (57 M€) fixed costs for the recycling plants, 26% (51 M€) transportation costs, and only 4% (9 M€) costs for waste disposal. The low disposal costs result from the small amount of disposed pd-AAC of only around 3%. Disposal costs are comparatively high (100 €/t), so that recycling is less expensive in many regions even though variable costs, fixed costs, and transport costs emerge. Areas, where all the pd-AAC is disposed of, can be identified when no recycling plant is located in the region, and there are no transports to other areas. This aspect is only the case in secluded areas in Scandinavia and Portugal and for the islands of Sicily, Sardinia, and Corsica (Figure 1). Overall, this recycling network (total costs of 200 M€) is much more cost-effective than disposing of all pd-AAC which would be around 338 M€, saving 138 M€.

It is also noticeable that only one large recycling plant with a capacity of 200,000 t/a is opened, and 46 small recycling plants with a capacity of 100,000 t/a are opened, resulting in a decentral structure of the recycling network. Savings in transport costs by shorter transport distances in a decentralised network outperform savings in fixed costs of larger recycling plants. Additionally, this discrepancy can be explained by the comparatively low waste generation of 3,382 kt, which is expected to increase significantly from 2025 (4,645 kt) to 2050 (11,010 kt). These rising waste quantities also impact the design of the recycling network (Figure 3).

**Table 2.** Key figures of an optimised European recycling network for pd-AAC in 2020, 2025, 2030, 2040, and 2050.

| key figure | pd-AAC network | | | | |
|---|---|---|---|---|---|
| | 2020 | 2025 | 2030 | 2040 | 2050 |
| total pd-AAC amount [kt] | 3,382 | 4,645 | 6,055 | 8,954 | 11,010 |
| total costs [M€] | 199.8 | 253.1 | 308.5 | 419.9 | 501.5 |
| variable costs [M€] | 82.2 | 114.8 | 149.7 | 222.7 | 274.5 |
| fixed costs [M€] | 57.2 | 78.8 | 95.2 | 125.2 | 146.4 |
| transport costs [M€] | 51.1 | 54.2 | 56.9 | 67.4 | 77.5 |
| disposal costs [M€] | 9.3 | 5.3 | 6.7 | 4.7 | 3.1 |
| number of small recycling plants | 46 | 64 | 71 | 86 | 92 |
| number of large recycling plants | 1 | 1 | 5 | 11 | 18 |
| total quantity disposed [kt] | 92.9 | 53.0 | 67.1 | 46.7 | 31.5 |
| share of disposed pd-AAC in total pd-AAC | 2.7% | 1.1% | 1.1% | 0.5% | 0.3% |

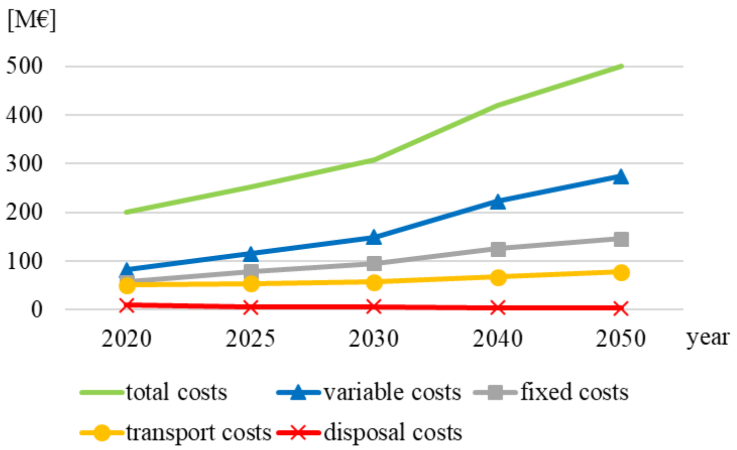


**Figure 2.** Development of the costs of the recycling network for pd-AAC in 2020, 2025, 2030, 2040, and 2050.

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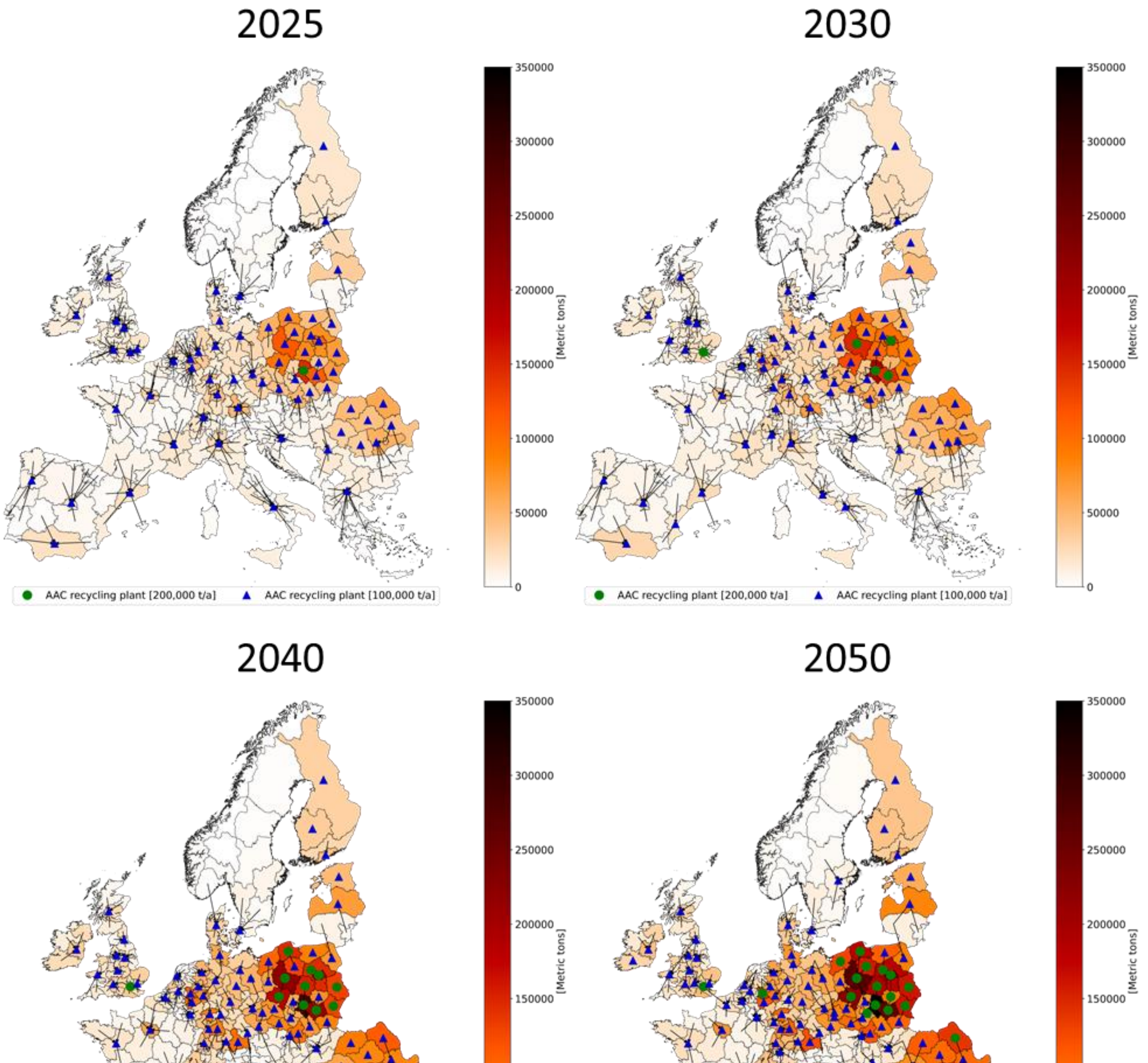


**Figure 3.** Optimised European recycling network for pd-AAC in 2025, 2030, 2040, and 2050 including small (blue triangle) and large AAC recycling plants (green circle) as well as transports between NUTS 2 regions (black connection line). The colouring of the maps reflects the expected annual pd-AAC amount from low (white/orange) to high (red/black).

More recycling facilities are opened in the 2025 network compared to the 2020 network. The number of smaller recycling plants increases to 64 and is complemented by one large recycling facility in Poland. Fixed costs increase by 38% to just under 80 M€ due to the placement of more small recycling plants (Table 2). Variable costs increase proportionally to the larger pd-AAC quantity, while transportation costs remain almost unchanged. Again, opening numerous small recycling plants and relinquishing economies of scale is preferred over larger transport distances and higher transport costs. The already low share of disposed pd-AAC even reduces to just over 1% in 2025, causing disposal costs of only around 5 M€. This decrease can be explained by the rising waste quantities leading to an economically reasonable opening of a small recycling plant in Portugal. Overall, the total cost of the network increases by only 27% while waste volumes rise by 37% at the same time.

Waste quantities further increase in 2030, 2040, and 2050 as shown in Figure 3 and more recycling facilities are opened accordingly. In particular, the number of large recycling plants with a capacity of 200,000 t/a increases in Eastern Europe, where most waste is generated. Waste quantities, especially in Poland, exceed 100,000 t/a in a single region, so a large recycling plant is needed to handle the whole pd-AAC. However, the network still shows a decentral structure. Besides, some smaller plants are added in Southern Europe (Spain, Italy, Greece, Bulgaria).

The share of landfilled pd-AAC in total waste continues to decrease over the years, reaching 0.3% in 2050. The more developed recycling network can explain this decrease. In 2050, the most significant cost increase compared to 2020 can be seen in the variable processing costs of pd-AAC (234%) due to the increased waste generation (226%). Fixed costs increase by 156% as 110 recycling plants are operated instead of 47. Transportation costs rise by only 52%, highlighting that the model keeps transportation distances comparatively low and favours a decentral recycling network. With a 226% increase in waste generation, total network costs only increase by 151% due to the economies of scale of the larger recycling facilities and by keeping transport costs low. Thus, the overall savings of the recycling network compared to disposing of all pd-AAC will also increase to 600 M€ in 2050.

## 4. Discussion

The model and the input data used in this study consider vital aspects of pd-AAC recycling. However, some assumptions had to be made. First, the model does not consider the demand for pd-AAC powder and granulate. However, including specific demand locations, especially AAC plants, would increase the model's informative value and allow a more precise placement of recycling plants and a better calculation of the total costs. Furthermore, regional cost differences were not considered. Especially the shipment costs, variable recycling costs and disposal costs are expected to vary regionally. Shipment and variable recycling costs may be lower in Eastern European countries with lower wages than in the rest of Europe. Additionally, countries with a lower population density could have lower disposal costs as the competition for land use might be lower. Generally, the cost calculation for AAC recycling is subject to high uncertainties as comprehensive studies are lacking. Finally, a reduced maximum disposal share was not considered. Only minimal quantities of pd-AAC are landfilled in the optimised model. However, banning the disposal of pd-AAC could significantly increase the recycling network's total costs as the model avoids transports over a significant distance or opening recycling plants in regions with a low pd-AAC volume through the current option of landfilling.

Besides, the model includes mass flow conservation, capacity restriction, and disposal limitations, but other extensions were not included. The recycling process could be modelled more precisely by implementing limited efficiency, respectively material losses in the process. Especially the purifying of the pd-AAC is mandatory to reach sufficient product qualities and inevitably involves material losses. However, the losses are expected to be limited. Furthermore, the recycling process usually produces fine AAC powder and coarse AAC granulate simultaneously. Both materials have very different characteristics and are used in different recycling routes. Different products can be modelled by a multi-mode extension. Such a model extension would also allow inclusion of demand locations. The model could also consider pd-AAC recycling options producing belite binders to substitute Portland cement [16] as a second recycling stage, leading to an overall three-stage model.

The results show a preference for a decentralised network, favouring the smaller recycling plants. However, the recycling network for 2020 includes regions where a small recycling plant covers a large area since the pd-AAC amounts are nowadays pretty low. In this case, transport distances are unusually long. Adding smaller plant capacities capacities would prevent these transport distances and build a more decentralised network. But, it would also need additional data, and the assumption of constant variable costs would be unrealistic for highly varying capacities. Currently, the maximum economically efficient transport distance for recycling in the model is 375 km considering disposal costs (100 €/t), variable recycling costs (25 €/t), and transport costs (0.2 €/t*km).

## 5. Conclusion

This study used a capacitated reverse logistics model with multi-sourcing and direct delivery, formulated as MIP, to design and optimise a new recycling network for pd-AAC in Europe. The pd-ACC waste generation in Europe is dominated by the UK, Germany, Poland, Czech Republic, Slovakia, and Romania. Therefore, the model also places most of the recycling plants in these countries. Initially, recycling plants of smaller capacity (100,000 t/a) are placed. With higher waste quantities starting in 2030, plants with a larger capacity (200,000 t/a) are also placed, especially in Poland. The recycling network is designed in a decentralised manner with numerous recycling plants, keeping transport distances relatively short.

Most of the network costs result from processing the pd-ACC. The variable processing costs also show the highest cost increases since the costs are proportional to the rising waste quantities. Fixed costs increase with the higher number of recycling plants and account for the second-largest share of total network costs. Transport costs are comparatively low due to the decentralised structure of the network. Overall, a 226% increase in waste generation from 2020 to 2050 results only in a 151% increase in total costs due to economies of scale in the fixed costs and transport costs kept low.

Future research should further investigate the economic aspects of pd-AAC recycling. More precise data on fixed costs of recycling plants and variable costs of AAC recycling with realistic economies of scale could be researched. Additionally, field data on transport costs, street distances and more specific locations would further increase the model's validity. Furthermore, model extensions can implement more aspects of the recycling process and existing facilities like AAC plants. And, the focus on the national level would allow a more detailed investigation.

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*sowie branchenbezogener, ökonomischer Anreizinstrument [Increasing the acceptance and use of mineral secondary raw materials, taking into account requirements relating to the protection of the environment and application, the potential economic benefits and sector-specific economic incentives] (Texte* 28/2012*)* (Dessau-Roßlau: Federal Environment Agency)

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