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Feeding Refineries

the extent and limitations of meeting European ethylene demand with agricultural residues

Philippa Roots

MNEXT WHITEPAPER | JUNE 2026

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HZ UNIVERSITY OF APPLIED SCIENCES

PREFACE

Before you lies the whitepaper ‘Feeding Refineries’ by Philippa Roots. Philippa is a researcher in the research group ‘BioBased Transitions’, which is part of MNEXT: the Centre of Expertise for the Materials and Energy Transition. One of Philippa’s interests is the equitable and sustainable use of residual biomass in its many forms.

This whitepaper was conceived as a thought experiment: given that a certain technology exists that can convert agricultural residues (think ‘straw’) into chemicals such as olefins, what will be the consequences? Is this logistically feasible? Can such technology provide new relevance to existing industry and capital assets? As Philippa notes: ‘Transitioning to bio-based chemicals and/or plastics is not simply a matter of technology, but of locating, collecting, aggregating, and preparing a vast amount of agricultural residues through a complex value chain spread out over new and existing infrastructure.’

In an age where every other day some company announces a factory closure or a move to China, and where the near-death of the European chemical industry has been announced, it is vital to look at what Europe has to offer to a post-fossil chemical world.

Critics will note that this ‘what if’ approach still assumes a world that needs (olefin based) materials. We think demand will still be there, but question the role of incumbent industries in making the switch is: perhaps the switch to bulk scale biobased chemicals is an opportunity for new companies, new business models and new ideas about the creation and distribution of value?

We hope you enjoy reading and look forward to your remarks, questions and criticisms!

Martijn Zieverink, professor of BioBased Transitions

COLOFON
This is a publication of MNEXT, Centre of Expertise for the Materials and Energy Transition of Avans University of Applied Sciences and HZ University of Applied Sciences.

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TABLE OF CONTENTS

INTRO

In the transition away from fossil carbon and the tightening of resource security, biomass is positioned as a solution for industry and society alike. Biomass has the benefits of being annually renewed, globally occurring, and carbon neutral, allowing local control over supply and captured value. At the scale of the global materials transition, however, biomass cannot be taken for granted. Carbon based materials are particularly reliant on biomass as an alternative to fossil fuels. The chemicals and plastics sector is projected to need 60 Mt of renewable carbon in Europe alone by 2050, with 20 – 25 % originating from bio-feedstocks (Plastics Europe 2022). In the simplest terms, this translates to 30 Mt of biomass, and likely an order of magnitude more.

Sourcing this amount of biomass for entirely new applications is more than an accounting exercise. The amount of biomass in use for chemicals today is relatively low, and the system of infrastructure necessary to reach 2050 goals does not exist. While technology for biomass-to-chemical conversion has been in development for decades and is maturing rapidly, less than 1 % of European chemicals and plastics are currently bio-based (Skoczinski et al. 2024). Nearly all planned or achieved capacity uses starches and sugars from primary crops (a smaller portion uses primary or recovered oils) and can take advantage of existing industry infrastructure. Biobased supply chain development on an European scale, and its implications, has thus far been little scrutinized past quantification (Carus et al. 2025, Harrandt et al. 2025).

This is especially true considering the shift in ambition from primary to secondary biomass as feedstock for future chemical production. Agricultural lignocellulosic residues (ALRs) from commercial crops are one of the most abundant and widespread sources of renewable carbon, but almost none of this carbon is currently upgraded into higher value products. While this lack of competition creates opportunity for biobased materials, it also requires a new connection between agriculture and chemical manufacturing that will influence the shape of both industries.

Utilization of ALRs for chemical production then presents a series of connected challenges. To begin, fledgling technologies need a stable supply of relatively clean and homogenous feedstock available in volumes to reach economies of scale and satisfy investors. Secondly, large refining facilities are immobile in traditionally strategic locations (Rotterdam, Antwerp, etc) and cannot be moved or replaced without losing large sunken costs. Thirdly, reaching sufficient volumes of feedstock to achieve scale will require large supply areas, limited in size by the ability and cost of transporting marginal biomass. As raw biomass is moved in contiguous trips, the cost and travel emissions of inefficient transport can overtake potential savings, limiting supply radius. However, the best supply areas June not be adjacent to existing industrial sites, requiring either long transport line or limiting the volume of product. Transitioning to bio-based chemicals and/or plastics is then not simply a matter of technology, but of locating, collecting, aggregating, and preparing a vast amount of ALRs through a complex value chain spread out over new and existing infrastructure. The design of this system will have vast implications on the ability of the chemical industry to transform itself for a fossil-free future.

In the following sections we describe a series of scenarios that outline one design of a biobased chemicals system. In doing so we take a bird's eye view to ask: how much biomass is available for refining; where is it in relation to refining infrastructure; and how does the spatial element of biobased feedstocks affect the feasibility of the transition? Rather than provide definitive answers, we aim to provide a new perspective on the codependency of technology, feedstock, and refining infrastructure.

SCENARIOS

Spatial mapping is an established approach to assess the viability of bio-resources (Comber 2015; Haase 2016) but has not been used regarding biobased chemicals. To apply the approach to this sector, we modelled three scenarios of residual agricultural biomass to ethylene production in continental Europe and the UK operating with near-future technology and infrastructure parameters. Using location toolboxes in ArcGIS, we showed how biomass can be distributed to processing sites at increasing levels of complexity, and what the implications are for the transformation of the industry. The goal is not to propose a functional infrastructure design or technological pathway, but to bring into focus the geographic and logistic bottlenecks of using residual biomass to make chemicals. Nevertheless we chose baseline parameters that reflect the state of technology and transport infrastructure now and in the near future (Figure 1).

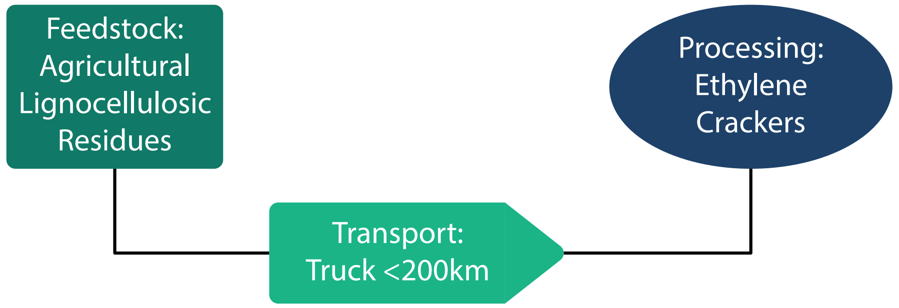

FIGURE 1

The baseline parameters of the study include the feedstock, the transport distance, and the location of the final processing facilities.

Feedstock: Agricultural residues can take many forms, but the largest group are the lignocellulosic stems and stalks of common staple crops, also referred to as straw. These agricultural lignocellulosic residues (ALRs) have a market value of 90-120 € t-1 dry matter and are otherwise used for animal bedding or disposed of (AHDB 2024). ALRs are a component of most field crops, mirroring the extent of commercial crops which are typically harvested once a year. In this project we used a dataset of ALRs derived from corn, wheat, barley, rye, rapeseed, canola, and oats grown in Europe at a resolution of t km-2 (Scarlat et al. 2019). Total t km-2 were reduced by the level needed to remain on the field to maintain soil fertility as per Scarlat et al. (2019). This limit keeps the scenarios from integrating net soil carbon loss into the output.

Processing: Ethylene is a platform chemical, and the largest single chemical market in Europe, typically produced via steam-cracking of naphtha at capacities of greater than 100kt/year (Cefic 2021). Due to the scale of the facilities and the benefits of conducting large scale processing at central hubs (Elbersen et al. 2022), we designed our scenarios with the assumption that final steam cracking takes place at existing ethylene crackers. In 2021 44 ethylene crackers were reported across Europe (Cefic 2021); although some have since closed or are scheduled to close these locations represent central processing locations.

Transport: A major non-technical hurdle of bio-feedstock utilization is the challenge of transporting disperse, low-density, and often wet biomass. As raw biomass is moved in contiguous trips, the cost and travel emissions of transport can overtake potential savings, limiting collection distance to a few hundred kilometers (Cintas 2021). For the purpose of our scenarios we assumed that ALRs are collected by the crop producer, dried on site, and transported by truck from a local storage site to the processing site with a maximum procurement distance of 200 km.

NOTE ON GEOGRAPHY

Throughout this paper the study area is referred to as ‘Europe’ or ‘European’. The definition we are using is spatial, to ensure data continuity within and between data sets. Therefore all countries on the sub-continent are included, while Russia, the Ukraine, and Turkiye are not. Ireland and the UK fall within scope but Iceland and the Faroe Islands are not included.

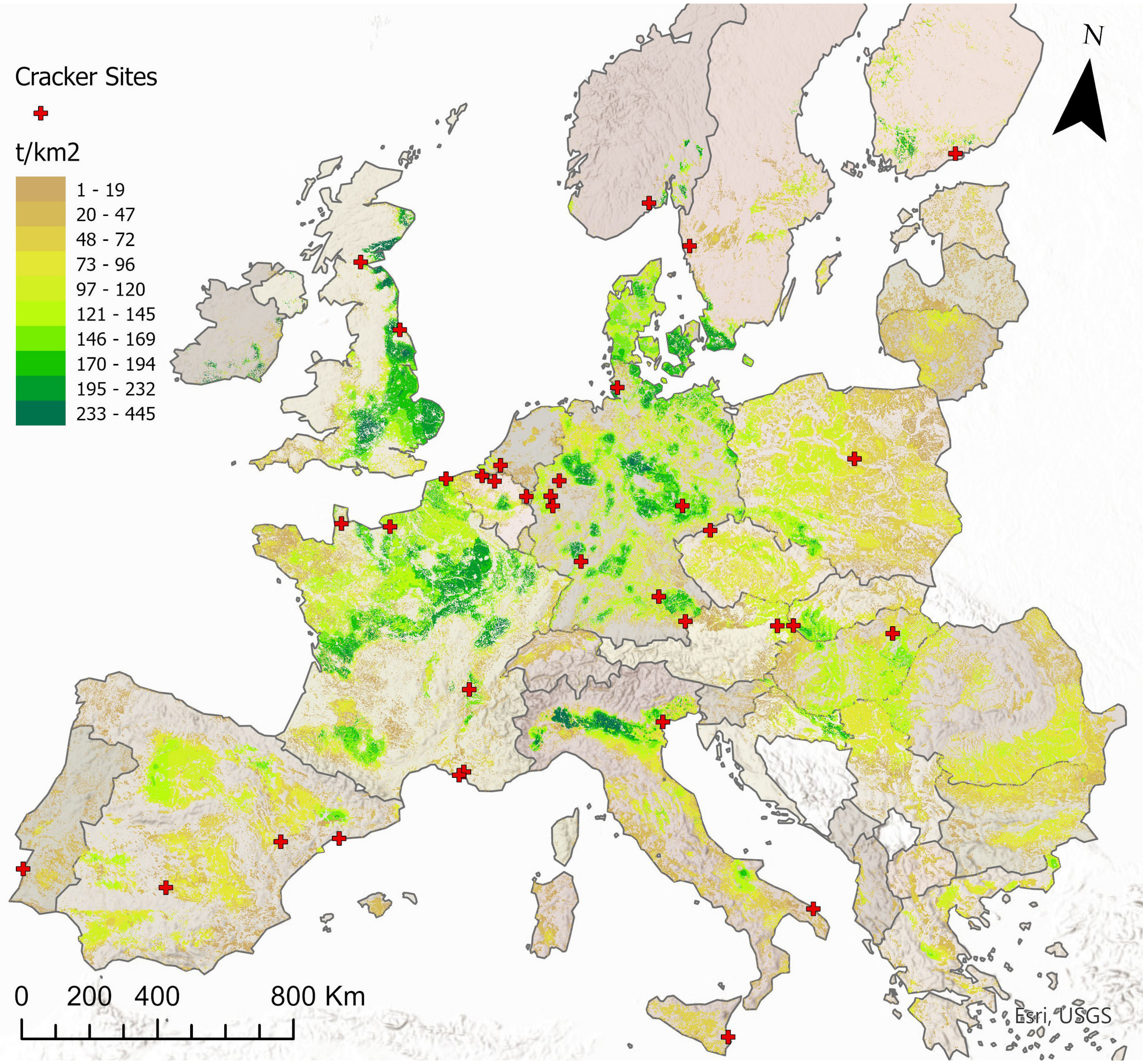

FIGURE 2

Agricultural lignocellulosic residues (adapted from Scarlat et al. 2019) are unequally distributed across Europe and do not align with cracking infrastructure. In addition to the distribution of agriculture, more ALRs are available where the soil is carbon rich and can tolerate a higher removal level. This results in the densest pockets of ALRs (in tonnes per km2) in France, eastern UK, Germany and Denmark, and south of the Alps. Existing refineries, originally built in proximity to ports, tend to be found in clusters and outside of agricultural areas.

HOW MUCH ALR FEEDSTOCK IS THERE?

Our first scenario sets the baseline for the scale of hydrocarbon product that could be made by calculating the amount of ALRs within a feasible transport distance of existing crackers using a theoretical conversion factor.

Lignocellulose is a complex organic molecule comprised of carbon, hydrogen, and oxygen, bound in a variety of configurations. However, for a high-level estimate, ALRs can be represented as generic biomass that is converted in perfect proportions to a generic hydrocarbon product. Vogt (2024) used the following assumptions to illustrate future biobased refineries: a molecular biomass weight of 30 g/mol carbon; a molecular product weight of 14 g/mol carbon; and a carbon conservation of 75%. The (optimistic) result is that 1 tonne of biomass can be converted into 350 kg of product.

Before calculating, a portion of ALRs must be conserved to maintain a minimum of ecological integrity. Although a residue, the non-food biomass has an important role in the carbon cycling of the soil. If removed entirely the soil will consistently lose organic carbon content more quickly than can be replenished during the growing season, leading to a drop in soil fertility (Scarlat et al. 2019). This is already observed in intensive agriculture systems, with many areas in Europe at risk of losing productivity in the coming decades (Afshar et al. 2025).

So how much can be removed for industrial use? Scarlat et al. (2019) answered this question on a granular scale by comparing crop cover to soil health for each square km of Europe, and calculating the amount of ALRs that must remain behind to maintain functional soil carbon levels (Figure 2). A total of 302 Mt of ALRs is reduced by 58% to 126 Mt, ranging from a strict 90% conservation in the Baltics to 50% allowable removal in Poland and Denmark due to ecological and historical factors. By using only this reduced, ‘sustainable’ amount, industry avoids additional impact on soil health and does not inherently exacerbate existing environmental problems.

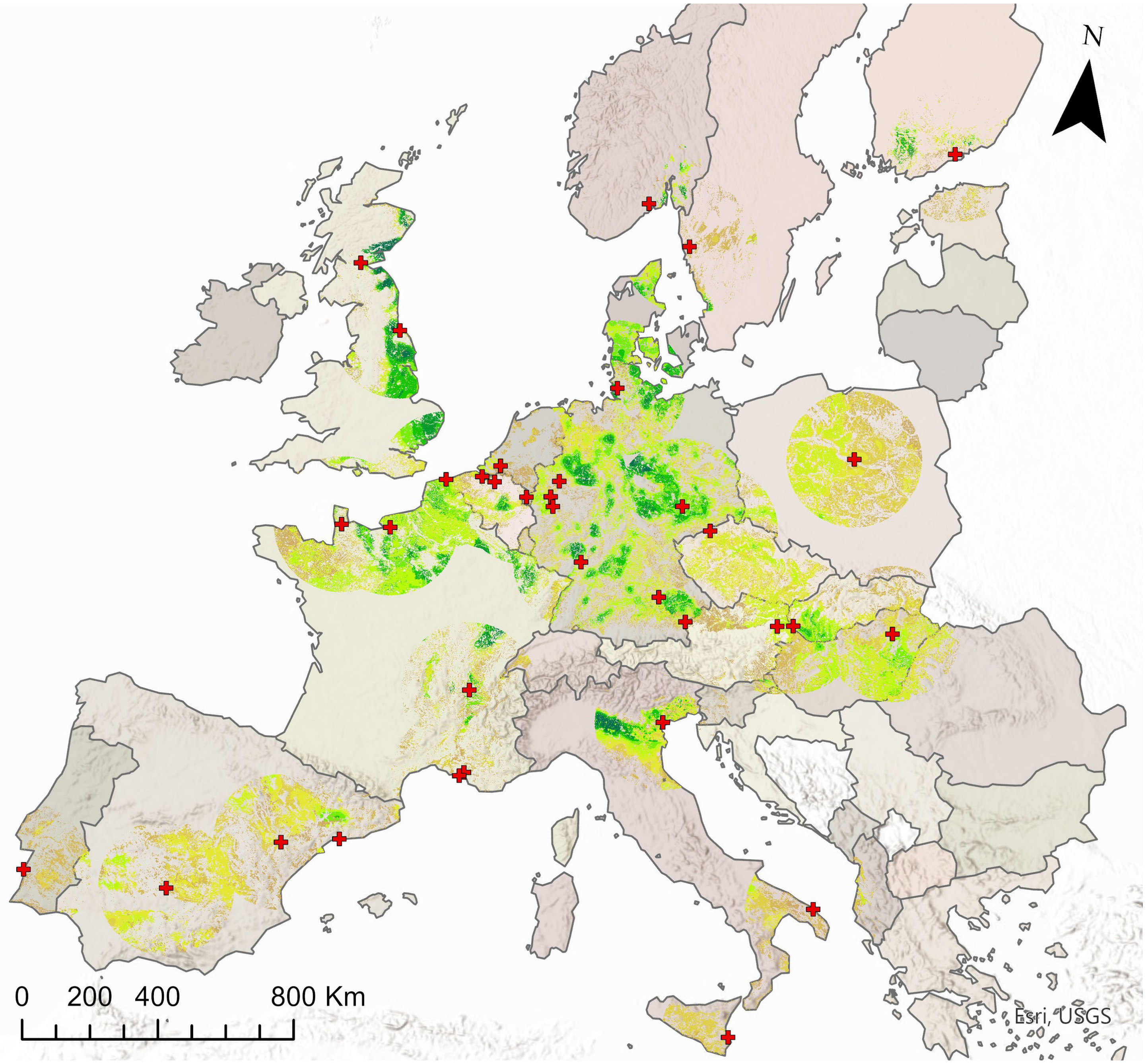

FIGURE 3

In **scenario 1** a 200 km supply radius around refineries includes roughly half of all sustainable ALRs (68 Mt). Some of the densest areas are excluded, such as western France, where no refining infrastructure exists. Crackers in northwestern Europe are much more aligned with ALRs than in the south, resulting in an uneven distribution of access to biomass.

	(dry) Mt ALRs	kt Product	% of 2023 ethylene Market (Cefic 2023)
Total Existing	302	-	-
Total Sustainable	126	44250	260
Scenario 1	68	23800	140
Scenario 2	51	2300	14

TABLE 1

ALRs and model output in the base case, scenario 1, and scenario 2.

With 35% conversion, sustainable ALRs in Europe could be converted to 44.25 Mt of hydrocarbon product, more than twice the current domestic ethylene market (Table 1). However once supply is limited to our 200 km transportation limit, the amount of usable biomass halves again to 68 Mt of ALRs and 23 Mt of product, with ALRs outside the supply radius considered 'stranded' and unavailable for industry (Figure 3).

This scenario, though unachievable without radical breakthroughs in technology, does represent a full transition, as no fossil feedstocks would be required to supply Europe with ethylene. It does come with more practical challenges. Within supply areas, the density of ALRs is not aligned with industry infrastructure; clustered sites in western Europe must compete for limited feedstock while solitary sites in central Europe have considerably more availability. Similarly, large pockets of biomass are found out of reach of industrial sites and are unlikely to be collected for that conversion purposes.

SUSTAINABLE BIOMASS AND RESIDUES

From an industrial perspective biomass is a 'free' source of carbon; since the carbon originates from the biosphere, process or disposal emissions from products are net-neutral. Released atmospheric carbon can theoretically be recaptured by growing new biomass in a fully circular system. Under intensive agricultural practices however, more carbon is lost to the atmosphere than is recovered.

The top meter of soil globally is a carbon stock several times larger than that of total aboveground biomass consisting of micro-organisms, mycelium, and un-decomposed plant matter. Conventional agricultural practices kill underground life and allow this biomass to decompose, leading to net carbon loss with every crop (Tegegn & Yadete 2024). This trend is not only concerning regarding climate change; depleted soil quality is linked to the decreasing nutritional value of staple foods and risk of crop failure (Afshar et al. 2025). So-called 'regenerative' practices, such as no-till, intercropping, and non-synthetic spraying, can halt and reverse soil carbon loss but are not yet widely used (Rehberger et al. 2023).

The agriculture sector must transform itself to survive, and efforts are underway, but if the materials industry aims to become a substantial client of agricultural carbon the responsibility must be shared. 300 Mt demand of unsustainably grown biomass will exacerbate existing problems; the same demand for regeneratively grown biomass will see ecological and climate benefits beyond simply removing fossil fuels. Ensuring that a minimum amount of plant matter remains with the soil, as is the baseline in this study, is only one strategy. Requiring that biomass suppliers use regenerative practices should become a standard in the new bio-economy, in addition to exploring how conversion by-products can enrich farm ecosystems.

HOW WOULD WE PROCESS IT?

In our second scenario we model fast pyrolysis conversion with spatial allocation to show the distribution of ALRs to existing crackers, and subsequent ethylene production with an existing technology. The minimize p-impedence model aims to maximize the distribution of a resource to final locations while minimizing total distribution distance. Following the findings of the first scenario only half of existing industrial sites can be chosen, allowing the model to disregard redundant and suboptimal sites while still maximising ALR allocation. Pyrolysis occurs on the same site as the crackers, and as the supply radius remains at 200 km, the highest amount of ALRs available is 68 Mt.

Several thermochemical processing routes are technically feasible to convert ALRs into ethylene. Fast pyrolysis was ideal for our 2nd and 3rd scenarios because it produces bio-oil, which can be co-fed alongside fossil naphtha into existing crackers, eliminating the need for entirely new refining facilities and allowing a gradual increase in production share. As a thermochemical process, pyrolysis also avoids the challenge of the low sugar found in lignocellulose, a common hurdle of 2nd generation feedstocks. Through pyrolysis 1 kt of dry biomass is converted to 500 t of bio-oil and 500 t bio-char (Bridgwater and Peacocke 2000). Bio-oil can then be fed into a steam cracker to produce 46,25 tonnes of ethylene as well as other olefins (Figure 4).

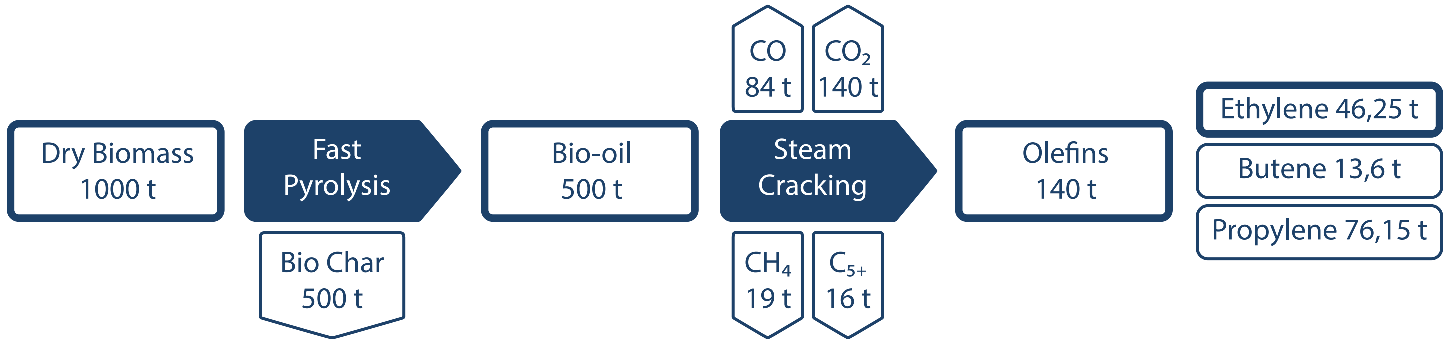

FIGURE 4

The conversion process of biomass into ethylene via fast pyrolysis adapted for this project. Bio-oil is converted into olefins (27 %), CO (17 %), CO_2 (30 %), CH_4 (3.7 %), and C_{5+} (3 %) (Zhu et al. 2025, Gong et al. 2011). In this mass balance 1000 t of dry ALRs produce 46.25 t ethylene, 13.6 t butene, and 76.15 t propylene.

When ALRs are converted via fast pyrolysis ethylene production drops to 2300 kt, roughly 14% of the baseline market (Table 1). The misalignment of ALRs and existing infrastructure is highlighted: the Benelux area can only provide enough ALRs for one small cracker (Figure 5). In order to simultaneously supply cracker sites in Belgium and the Netherlands considerably long supply chains for biomass would have to be developed, likely connected to the port system. Another noticeable outcome is the distribution of ethylene between sites; central and eastern Europe have the largest sites while western and southern sites are relatively smaller.

The volume of bio-oil produced at each location is quite low compared to typical cracking feed volumes. Because it is not necessary to run a cracker on 100% bio-oil a mix together with fossil naphtha is more likely. In this scenario the addition of ALR-based ethylene does not cause a full transition, but allows conventional fossil crackers to continue operating with slightly lower embedded emissions.

WATER

To allow any level of movement, biomass must be at least partially dried on site; transporting the associated water would otherwise be cost-prohibitive. Valorizing dry biomass however still involves the relocation of another type of water: virtual water.

Virtual water is the H_2O embedded in a product through production or processing (Hoekstra & Hung 2005); water that is consumed by crops and stored in plant cells in an organic form, in our scenarios later converted to a hydrocarbon product or by-product. As the water is sourced through rain or groundwater in the growing region and 'consumed' by end-users elsewhere, this represents a flow of water from one region to another, potentially across continents.

The trade of virtual water has traditionally been understood as both a mechanism for water-poor regions to alleviate their water consumption by importing goods from water-rich regions, and as an exploitation risk for rich countries to obtain resource-heavy products without draining their own watersheds (Mekonnen et al. 2024). Which mechanism is in play in valorizing residual biomass for materials remains to be seen, but as our scenarios show the movement of mega tonnes of previously stationary biomass across Europe, it is no small flow. Particularly as climate change upsets global water systems, the topic deserves close scrutiny as biomass is utilized at scale for new global purposes.
ecosystems.

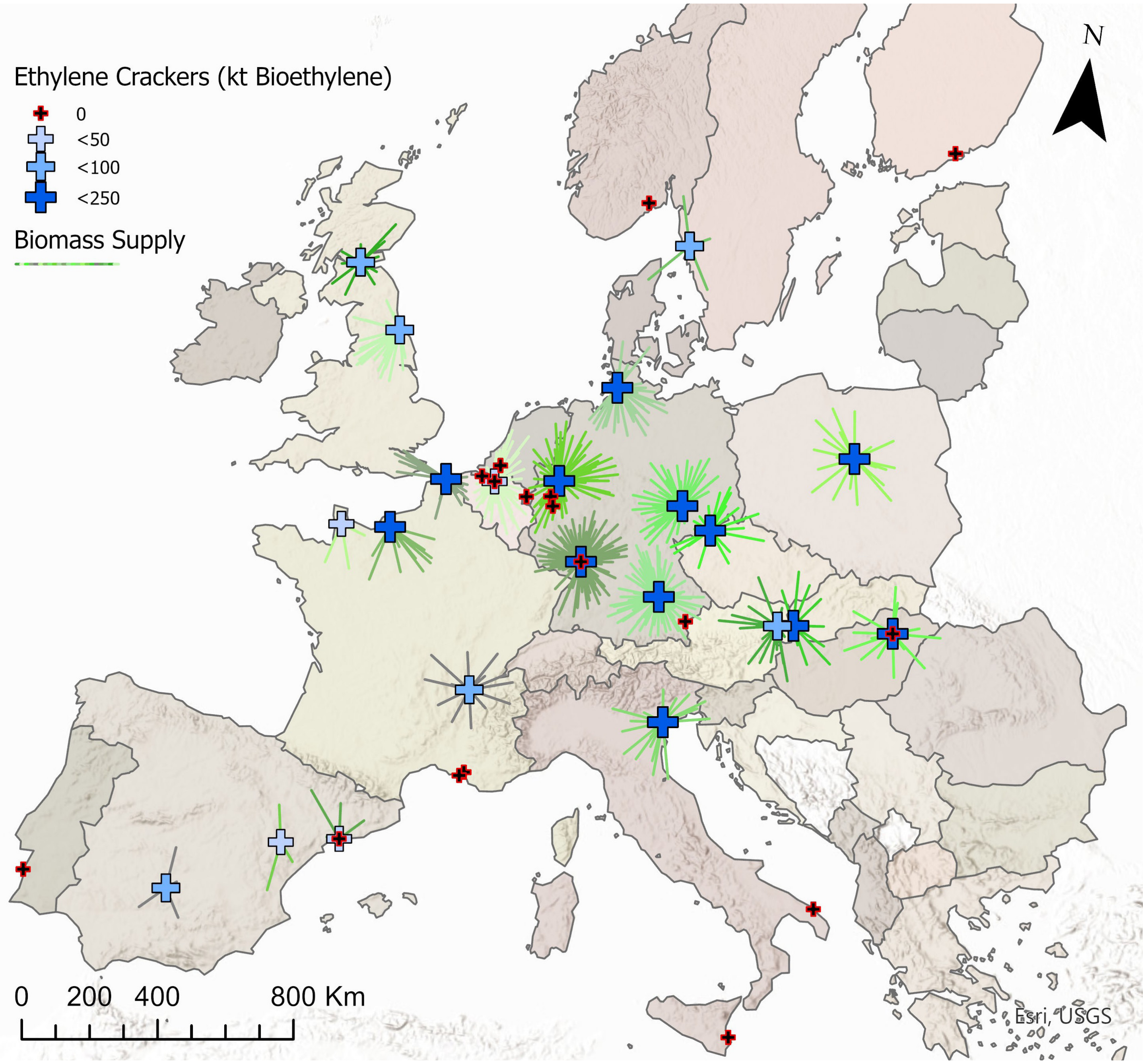

FIGURE 5

Spatially allocated ALRs in scenario 2 illustrates where refineries would draw their feedstock from if they were to produce bio-ethylene. Each line a supply line of ALRs; the size of the cross is proportional to the amount of bio-ethylene possible. Out of 44 possible crackers only half (22) were allowed in the solution to permit for the rejection of redundant or sub-optimal sites. Redundant sites are primarily found in the Benelux area, where many crackers are clustered together without high ALR density. In southern and northern Europe too little biomass is in proximity to refining locations; these sites could operate but would be very small. Via fast pyrolysis scenario 2 could produce 2300 kt bio-ethylene with 40% (51 Mt) of total ALRs.

HOW WOULD WE MOVE IT?

As seen in the first two scenarios, roughly half of ALRs in Europe are found more than 200km from existing industrial areas, preventing their use. While the low density of raw biomass limits transport to short haul trucks, the intermediate product of pyrolysis, bio-oil, could be transported much further by pipeline. Therefore in our third scenario we modelled a multi-model supply chain with new pyrolysis facilities placed strategically between cracker sites and ALR hotspots (Figure 6).

Pyrolysis locations were selected within the model from a set of 250 potential options semi-randomly located to maximize spread while remaining within the transport limitations. A specified number of pyrolysis location solutions were then chosen by the model (step 2) to minimize total transport distance while allocating biomass A third step allocated the output of the pyrolysis solution to existing cracker locations to again minimize total transport distance. The model ran several times to assess the effect on production volume, transport distance, and facility size. We tested these relationships allocating ALRs to a set of 20 (A), 40 (B), 80 (C), and 100 (D) pyrolysis sites across Europe. In each set the model chose from a bank of potential locations to optimize total biomass coverage within the transport distance.

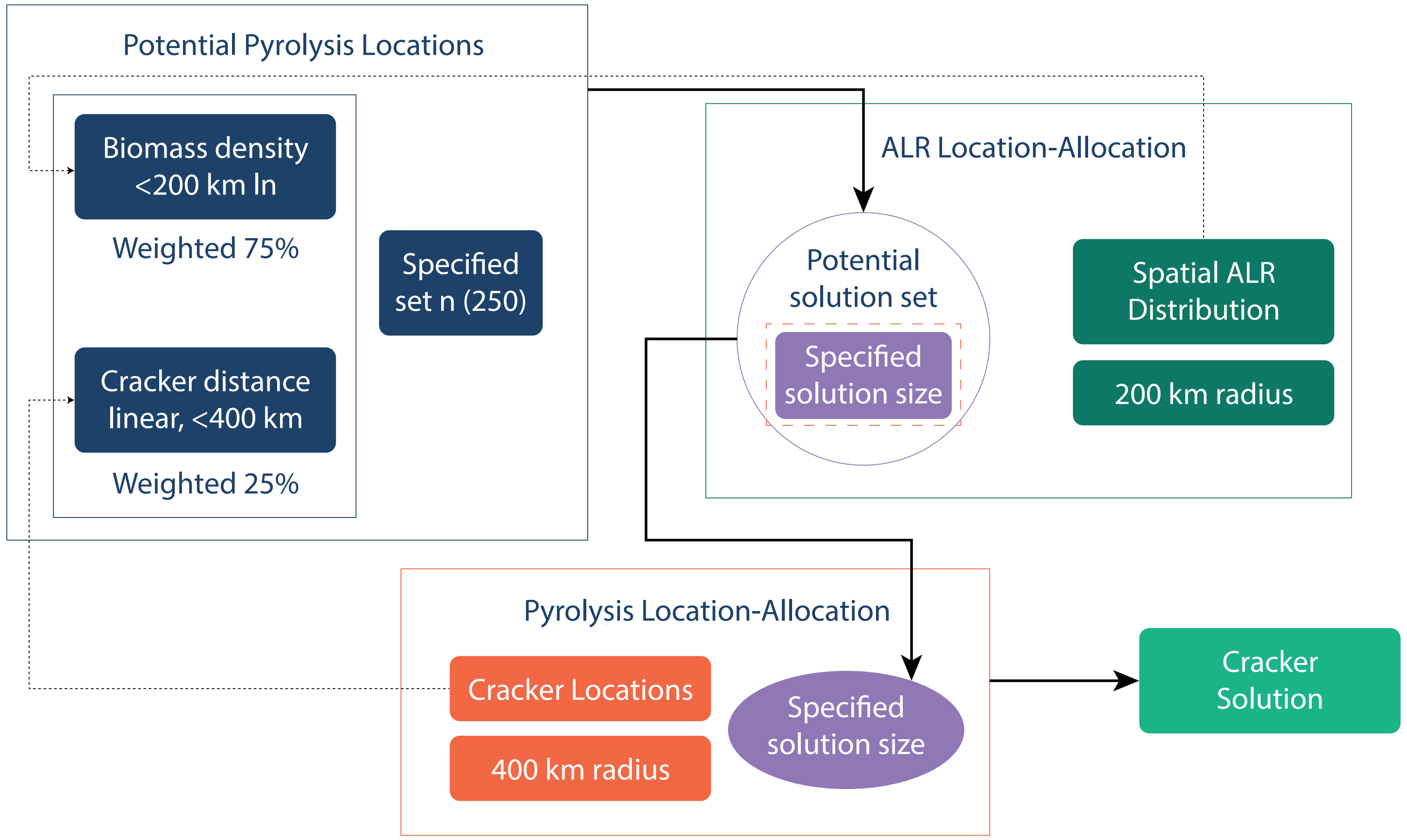

FIGURE 6

The spatial allocation model consisted of three elements: a set of potential pyrolysis options, the spatial distribution of sustainable ALRs, and the existing cracker locations. We ran the model several times with different sizes of pyrolysis sets.

TABLE 2

The results of four scenario 3 alterations with different numbers of pyrolysis facilities.

Scenario	# of pyrolysis facilities	% of total ARLs	total bio-oil capacity (kt a⁻¹)	median bio-oil capacity (kt a⁻¹)	# of cracking facilities in solution	total ethylene capacity (kt a⁻¹)	average km t⁻¹ ethylene	% of 2023 ethylene market (Cefic 2023)
A	20	66	41770	1987	17	3864	93	23
B	40	85	51590	1227	25	4772	108	28
C	80	92	53100	521	27	4912	112	29
D	100	92	53740	466	28	4971	102	29

Predictably, overall biomass coverage rose with a greater number of facilities, while median capacity size dropped (Table 2). Maximum facility size however remained relatively similar across A, B, and C scenarios (Figure 7), suggesting that a few select areas in Europe (central Germany, western France, and the UK) can support a very large pyrolysis facility.

With the addition of pyrolysis sites 66% of ALRs can be reached in scenario A, rising to 85% in scenario B. After 80 facilities (92% of ALRs), additional facilities split rather than increase overall coverage, implying the remaining 8% is not feasible to obtain. Capacity size is relatively low with 80 facilities however, with less than half reaching 500 kt bio-oil production per annum. Comparatively, all but two facilities in scenario B are over 1000 kt (Figure 8). Capital investment is more favourable for larger production volumes, and with a platform chemical such as ethylene pyrolysis facilities much smaller than 400kt June be uneconomical to build (Elbersen et al. 2022). Pipeline connections between the new facilities and existing crackers could be repurposed from the current pipeline network or newly constructed; for pipelines over 100 km additional pumping stations would be needed.

Transporting straw by truck limits the collection area to the economically feasible distance, leaving hotspots of biomass production out of reach and 'stranded' (Elbersen et al. 2022). With 40 pyrolysis facilities approximately 15% of available biomass remains out of reach; this proportion would highly depend on the value of ALRs as a feedstock compared to the cost of marginal transport. The relationship of transport kilometers to product also changes as the number of pyrolysis facilities rise. As collection areas become slightly smaller average supply distance decreases, but this is offset by ineffectively placed facilities which incur long transport lines for relatively low volumes of biomass. In practice transport must follow existing roads, lengthening travel routes over 200 km; these scenarios represent the upper bounds of such a limit. The 200 km biomass supply radius already is near the upper limit of truck transport for unprocessed biomass (Elbersen et al. 2022, Cintas 2021). Even with optimized collection routes, the sheer number of trucks (around 600/day to a median pyrolysis facility given average ALR density) would require significant management and road maintenance.

CO_2

The largest driver and goal of the materials transition is reducing industrial CO_2 emissions and their contribution to climate change. CO_2 emissions broadly come from three sources during the thermochemical production of platform chemicals: process emissions from refining carbon feedstock, emissions from creating energy (mostly heat) to power the process, and emissions from activities such as plant construction, transportation, business operations, etc (Tavella et al. 2025). The first and second create the vast majority of industrial greenhouse forcing and are considered difficult to mitigate as they are inherent to the refining technology.

Replacing fossil carbon with biogenic carbon in industrial processes does reduce emissions but is not a panacea. While the CO_2 released through combustion June be net-neutral, process heat is still necessary for refining and remains difficult to generate from renewable sources. Furthermore, the additional transportation of biomass (in this case by truck) could reduce or outweigh the carbon savings of bio-ethylene if it still relies on fossil fuels. The materials transition must consider more than a different feedstock in order to design a truly carbon-neutral system.

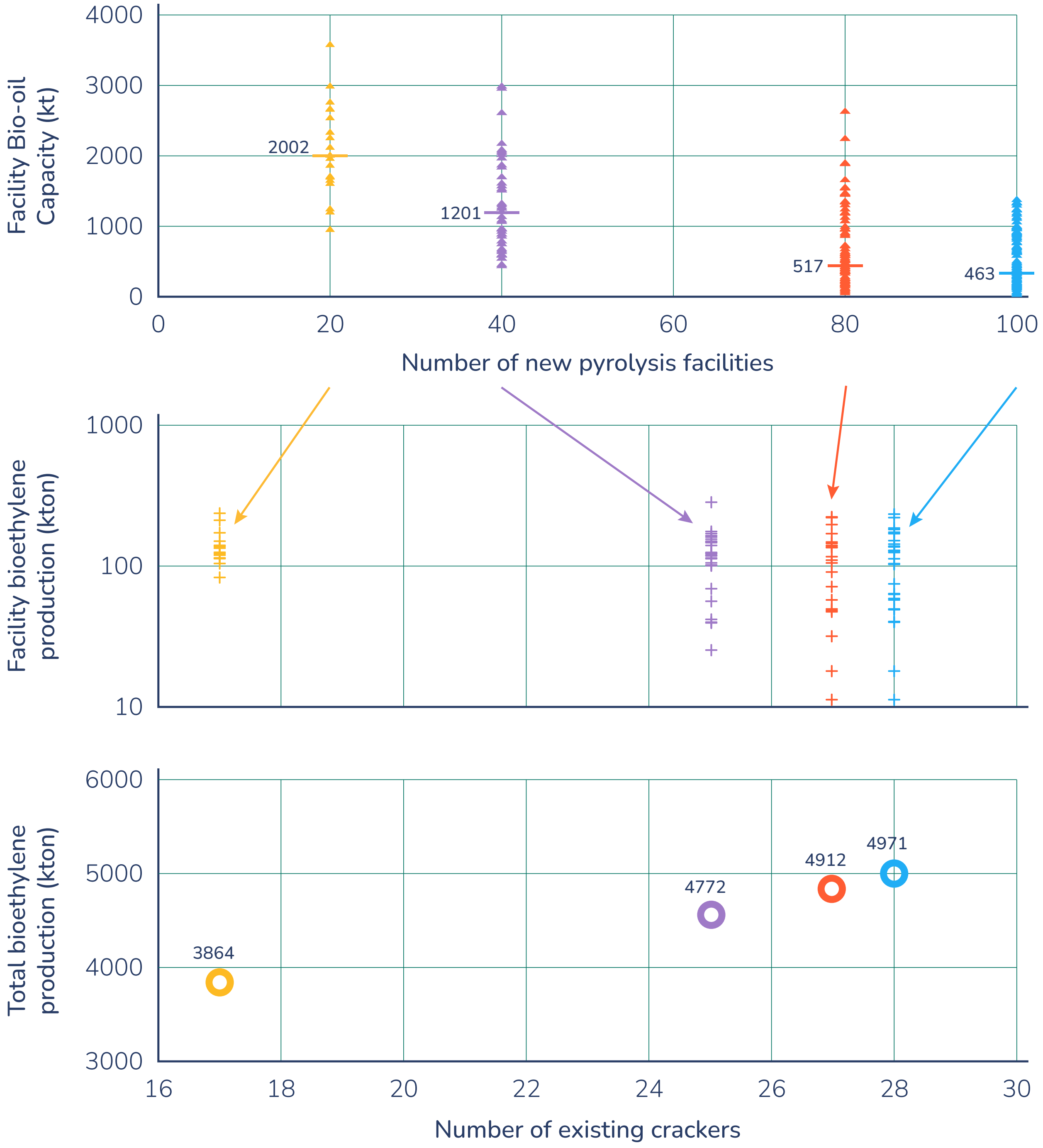

FIGURE 7

Capacity of bio-oil (7a) and bio-ethylene (7b) at individual facilities in each scenario 3 solution. Median capacity of pyrolysis facilities (the solid line) decreases as the number of sites increase, with 20 (A), 40 (B), 80 (C), and 100 (D) facilities distributed across Europe in scenario 3 respectively. Even solution A results in a higher proportion of ALRs accessible (66%) compared to crackers alone; this rises to 92% in D. Although mean pyrolysis capacity in C is ~1/4 of A, the first three distributions all have a few sites much larger than the rest. Of the 44 existing cracker sites, solution A only used 17, B 25, C 27, and D 28; the rest were redundant and did not improve efficiency. The total amount of bio-ethylene possible increases as more sites are added (7c), but the marginal effect is small after 40 sites.

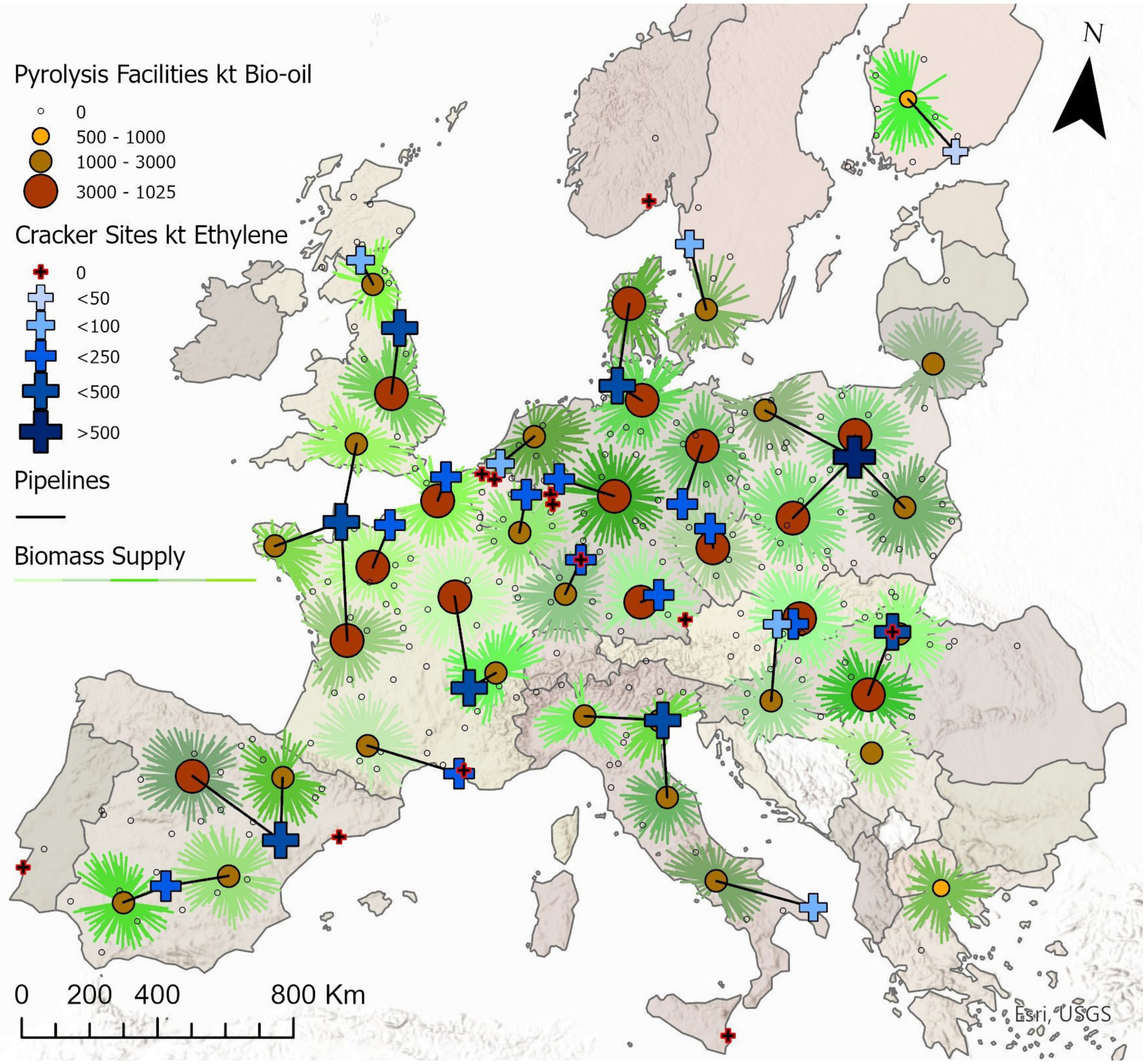

FIGURE 8

Distributing 40 new pyrolysis facilities strategically between existing refining infrastructure and dense supply areas in solution B allows for 85% of sustainable ALRs to be processed within 200 km of their origin. As a result biomass use is geographically consistent and pyrolysis facilities are spread relatively evenly across Europe. Each facility is within 400 km of an existing cracker, allowing bio-oil to be transported via pipeline. In many cases a cracker is fed by a single pyrolysis facility; these systems would be highly co-dependent and location could be further optimized.

HOW SOON AND HOW EFFECTIVE?

We assessed the scenarios outlined above on a spectrum of feasibility and transformation potential (Figure 9). Feasibility is defined by both the advancement of technology required, and the level of infrastructure investment needed. Scenario 1, with perfect biomass to hydrocarbon conversion, relies on technology that does not yet (and perhaps cannot) exist and is thus placed in the 'far-future' side of the spectrum. Scenario 2 uses fast pyrolysis conversions that have been demonstrated at lab and pilot scale and could conceivably take place in the near future with relatively little effort, as bio-oil would be produced and consumed alongside fossil naphtha and at the same location. Scenario 3 uses the same technology, but with the construction of new pyrolysis locations and many hundred kilometers of pipeline connection, would require considerable investment and could not be completed within at least a decade.

Transformation potential can be understood as disruption to business as usual to both the fossil chemical industry and to conventional agriculture, eventually resulting in entirely new systems with new actors and connections. In scenario 2 and 3 disruption to industry is not complete; adding bio-oil to fossil naphtha does not allow existing crackers to completely change their feeds and June even prolong their activities by 'greening' their inputs. Additionally, without a full technological change the option remains to switch back to fossil feeds at any time. Regulation already favours a mass balance approach where certain products can be marketed as bio-based in proportion to the mix of overall bio-feedstocks (ISO 22095, 2020), allowing differentiation in niche and high value markets. While this does reduce the absolute volume of fossil feeds and raises consumer awareness of biobased products, it does not force investment into alternative processes, and June even prevent more transformative technologies from gaining a foothold.

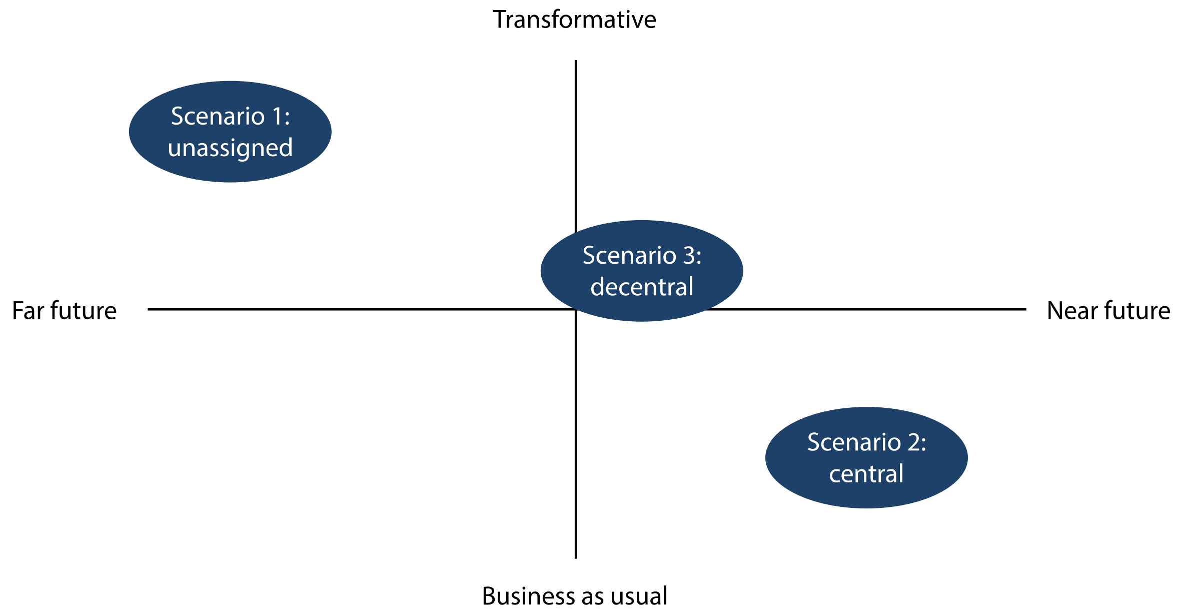

FIGURE 9

The three scenarios, with unassigned, central, and decentral processing, can be described on a spectrum of their potential to transform the chemical system and how soon in the future they are feasible. Speed is irrelevant if the effects are not transformative, and the best system has no effect if it cannot be achieved in a timely manner.

In scenario 3 the increased degree of decentralization and possibility of midsized crackers fed entirely on ALRs increases the distance from the current system. This is limited by the scale requirements of pyrolysis; an alternate technology such as torrefaction could allow even more decentralization and greater producer influence over the supply chain and the value it creates (Riese et al. 2024). In all scenarios many existing crackers are made redundant due to their geography, showing the possibility of 'losers' that are less suited to transition to ALR (or main crop) based feedstocks at all.

The potential to disrupt agriculture business as usual is less clear. The production of ALRs as used in our scenarios relies on industrial monocropping, where one species is grown over a large contiguous area and treated with synthetic biocides and fertilizers (Belete and Yadete 2023). Due to the volumes required to reach commercial scale and the investment involved in collection, large farms producing the same staple crops over multiple years would gain an economic advantage. Continued or expanded monocropping is threatening to European climate and nature goals as this system is inherently unsustainable (Afshar et al. 2025; Belete and Yadete 2023) and creating decades long demand from industry could lock-in agriculture from transitioning to more ecological practices.

In all scenarios this agricultural system is assumed to continue, but it's effects could be mitigated by the decentralization of intermediate processing in scenario 3 and subsequent potential to return by-products to growing regions. The main by-product of pyrolysis, biochar, has industrial uses in filtration and decontamination of effluents and soils and is gaining traction as an agricultural supplement to improve water retention and soil fertility (Curcio et al. 2025). A closed loop system returning biochar back to ALR source fields June allow for greater proportions of ALRs to be removed without harming soil longevity, thus increasing overall ethylene volumes while reducing impacts.

In summary, our study has shown that fast pyrolysis conversion of agricultural residues, with some degree of decentralization, could replace between 20-30% of current ethylene production in Europe using available technology. This set-up would necessitate building around 40 large scale pyrolysis facilities and several hundred kilometers of pipeline, as well as the movement of thousands of trucks. Industrial agricultural would see additional income and the possibility of a non-synthetic soil supplement (biochar). Undertaking these investments would put the chemical industry in line with renewable feedstock targets but would fall short of fully transforming either industry.

Due to the disperse nature of ALRs, the ability to decentralize and supply processing facilities with 100% biofeedstocks with limited transportation would facilitate greater and more irreversible transformations. Beyond simply optimizing the conversion ratios of a given technology, future solutions would benefit from ensuring their compatibility with the design of their feedstock system.

We hope our study brings another perspective to the challenge of de-fossilizing the (carbon-based) chemical industry and inspires a framework to consider the logistical ramifications of bio-based feeds and technologies.

The Feeding Refineries study was made possible with funding from SIA GoKiem. Special thanks to project partners Looop and Biogrowth Development, and to Renzo Akkerman and Arjen van Vliet for sharing their expertise. Thank you to Arjen Boon, Bas Koebrugge, and other colleagues at MNEXT for help with editing and layout, and to Martijn Zieverink and Nathalie Márquez Luzardo for their assistance throughout the project and contributions to writing.

A version of this whitepaper will appear in an upcoming issue of Chemical Engineering Transactions Journal (AIDIC).

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