Fair Finnish Footprint

Finland's pathway to consumption aligned with global sustainability boundaries

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Executive Summary

The global environmental crisis calls for immediate and decisive actions to preserve ecosystems, biodiversity, and human well-being

Around the world, we are facing an unprecedented environmental crisis, with human consumption significantly exceeding global sustainability boundaries, leading to dire consequences for ecosystems, biodiversity, and human well-being.

Humanity's pursuit of resource-heavy economic development and reliance on resource hungry industries have altered roughly 75% of the planet's land surface[1], causing biodiversity loss at rates previously unseen in human history. However, the ongoing consumption focused economy is a relatively new phenomena in the human endeavor.

This degradation from overconsumption poses a threat not just to nature but to humanity as well. Moreover, overconsumption is the fundamental driver of climate change and biodiversity loss. Recognizing its urgency, the World Economic Forum has identified "Critical change to Earth systems" as one of the top risks within a decade, indicating that significant impacts could occur much sooner than expected[2]. Already, environmental degradation affects the well-being of over three billion people and costs at least 10% of the annual global GDP in lost ecosystem services[3].

Immediate and decisive actions are necessary to curb this alarming trend. These actions encompass protecting high conservation value areas, rehabilitating vast areas of land and marine ecosystems, and significantly reducing the consumption of natural resources. Implementing these protective measures, driving ecological restoration, and transforming consumption patterns and structures are essential steps towards halting and reversing the loss of nature and biodiversity. Such united efforts are imperative for ensuring a sustainable future for all forms of life on our planet. One of the targets in the UN Biodiversity agreement (Kunming Montreal Biodiversity Framework), signed in 2022, calls countries to "reduce the global footprint of consumption in an equitable manner" by 2030. In this report, we suggest actions and goals for this task.

The Fair Finnish Footprint offers an analysis of Finland's footprints compared to global sustainability boundaries and peer European countries with detailed insights into how collective and individual efforts could improve Finland's sustainable development. To our knowledge, this is the first report ever analyzing multiple footprint measures in this context. It presents a compelling case for action, providing elements for change to reduce Finland's excessive natural resource consumption as well as outlining the benefits of embracing sustainability.

This report invites the reader to explore how Finland can achieve sustainability by leveraging both national and EU policies and the crucial contributions of its citizens and businesses. By adopting such measures, Finland could aim not only to meet but also to set a precedent in achieving global sustainability boundaries.

Finland surpasses the global sustainability boundaries in all footprints, with our Material, Biomass, and Nitrogen footprints considerably exceeding European averages

Finland, known by many for its vast forests, thousands of lakes, environmentally friendly policies, and sustainable nature management, is in reality overconsuming its natural resources compared to both global sustainability boundaries and other countries in Europe. The Fair Finnish Footprint analysis looks at five critical dimensions – Material, Biomass, Ecological, Phosphorus, and Nitrogen – and reveals that Finland surpasses extensively the sustainable global boundaries in every dimension. The five footprints represent the total pressures of Finnish human activities on natural resources and ecosystems (excl. greenhouse gases, given their coverage in other reports).

The footprints measure the consumption of resources against global sustainability boundaries. In a simplified way, global sustainability boundaries are defined by allocating resources on a per capita basis globally so that all people have equal access to natural resources. More details can be found in the Footprint definitions chapter.

Finland's Material, Biomass, and Nitrogen footprints present a significant concern as they are fundamentally unsustainable and surprisingly higher than the European averages. Notably, Finland's Material and Biomass footprints are among the highest in Europe. This can be partly explained by the country's economic dependence on resource heavy industries and construction, which are currently operating on unsustainable levels. Nevertheless, current economic structure is not a justification for excessive overconsumption of natural resources.

Additionally, one clear example of Finland's environmental pressures can be seen in the state of the Baltic Sea. The Baltic Sea is currently in a critical condition, dealing with widespread harmful algal blooms and seven of the world's ten largest marine dead zones. This situation is driven by eutrophication, which is fueled by excess nitrogen and phosphorous use. The main sources of these nutrients include runoff and leaching from agricultural and forestry activities.

Finland's large footprints cannot be fully explained by factors such as population density, geographical latitude, or industry profile. Rather, Finland's footprints are driven by excessive consumption of raw materials. This excessive consumption starkly contrasts with more sustainable practices seen in other European countries, highlighting the need for Finland to reduce its resource use to align with global standards. However, still Finland's European peers are not within the global sustainability boundaries, suggesting further policy measures are needed both in Finland and across Europe.

Reduction of Finland's environmental footprint calls action from policymakers, supported by combined efforts from private enterprise and individual consumers

Reducing Finland's footprints is crucial for reversing nature and biodiversity loss both domestically and globally. Bringing Finland's footprints within global boundary limits will require ambitious policies impacting every aspect of life. Policy measures will need to identify and discourage negative externalities while encouraging actions with less harmful effects.

Consumption in Finland has widespread impacts that contribute to the depletion and harm of ecosystems in other countries. This also highlights the need for a broader look at Finland's environmental impact, acknowledging the global footprint of its consumption habits. Broadening our understanding and discussion about the worldwide implications of consumption encourages a shift towards more sustainable practices, not only within Finland, but beyond its borders as well. However, this report focuses mostly on domestic consumption and fixes within Finland it could employ.

Policymakers must ensure that this transition is equitable, spreading the reduction efforts across all sectors. While all industries are accountable for their environmental impact, those with larger footprints and greater negative externalities are particularly suited for transformative change. This ensures equitable participation and benefit for all stakeholders involved.

Policy measures must be carefully designed to align with Finland's economic and social frameworks. Implementing a balanced strategy is essential for achieving footprints limited to the global boundaries. This would not only align with Finland's reputation as an environmentally progressive country but also secure the long-term viability of national and global natural resources and ecosystems.

To align with global sustainability boundaries, Finland would need to employ transformative policies that aim to reduce overconsumption across all five footprints

As highlighted, Finland's high footprints are primarily driven by excessive consumption of physical resources, starkly contrasting with global sustainability boundaries. Moreover, the so-called national Dasgupta Review[4] showcases how Finland's economic structure, which currently inadequately accounts for environmental costs and biodiversity loss, necessitates urgent, transformative changes to align future development with sustainable limits. The resistance to such changes is fueled by entrenched cultural norms, economic incentives, and vested interests that sustain current unsustainable practices.

Transitioning to a sustainable economic model requires not only new business models that respect global sustainability boundaries but also a concerted effort from all societal sectors to overcome the inertia of existing systems and drive Finland towards sustainability. However, these transformative measures may have economic and social implications as old practices and business models are replaced by more sustainable ones.

To balance these effects, Finland would need to implement policies that realign economic incentives to acknowledge the value of nature and support pioneers of sustainability. This strategy encompasses promoting established sustainable practices and regulating detrimental ones, as exemplified by Finland's successful advancement in renewable energies like wind among others, supported by strict regulations and incentives to phase-out harmful fossil energy sources.

The chapter discussions for the five footprints primarily focus on near-term fixes that are attainable within the current economic context, highlighting practical and immediate measures to mitigate Finland's environmental impact. Finland can draw lessons from European counterparts to implement policies that reduce the footprints towards leading European countries in the respective footprints. These policies, while not fully achieving global sustainability, provide effective and measurable solutions.

In contrast, the concluding chapter on 'Pathways for Finland's footprint reductions' shifts towards a more transformative approach, delving into long-term fixes and broader systemic changes necessary to align Finland's practices within global sustainability boundaries. Three critical policy strategies are raised in this section: curtailing overconsumption by costing-in environmental impacts of material use, improving material circularity, and ensuring fair and just transition.

The consequences of inaction are severe, threatening our future economic stability and ecological well-being. Now is the time for decisive, collaborative, and policy-supported actions to ensure Finland's sustainable and prosperous future.

Finland's Footprints

Material footprint[1]

Tonnes per capita

36.5
Finland

5.0
Global boundary

Description

Total raw materials consumed in products and services

Primary drivers for Finland

- Use of construction sand and gravel

Biomass footprint

Tonnes per capita

6.0
Finland

1.2
Global boundary

Description

Total organic regenerative materials consumed

Primary drivers for Finland

- Wood products for manufacturing
- Energy production

Ecological footprint

Global hectares per capita

5.4
Finland

1.5
Global boundary

Description

Total land and water usage for consumption or development

Primary drivers for Finland

- Carbon uptake land needed

Nitrogen footprint

Kg per capita

50.5
Finland

7.8
Global boundary

Description

Total fertilizer-based nitrogen application (excl. manure)

Primary drivers for Finland

- Agriculture
- Industry and urban areas

Phosphorus footprint

Kg per capita

3.2
Finland

0.8
Global boundary

Description

Total fertilizer-based phosphorus application (excl. manure)

Primary drivers for Finland

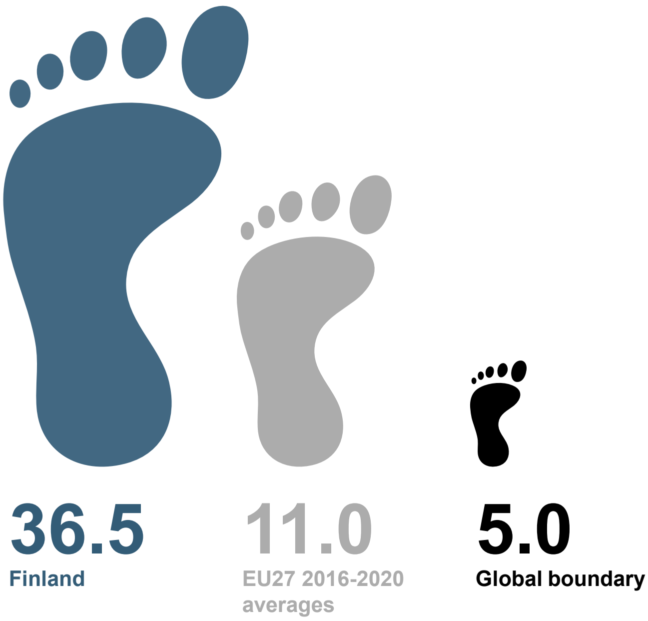
- Agriculture
- Forest industry

1. Excluding biomass
Note: Finland's Material and Biomass footprints (average 2016-2020); Ecological footprint (2022e) Nitrogen and Phosphorus footprints (2015)

Material Footprint

Finland's Material footprint is seven times higher than the global sustainability boundary

The Material footprint measures the total amount of raw materials we extract for producing goods and services consumed in Finland. The footprint consists of four main resource categories: non-metal ores (sand and gravel, stone, and other non-metallic materials), metal ores, biomass (wood-, and plant or animal-based products), and fossil materials (Figure 2). This metric includes all non-recycled raw materials used in domestic consumption and excludes exports.



In this report, Biomass is excluded from the Material footprint and addressed separately given its relevance in the Finnish context. However, it is important to remember that typically (e.g., in the global Sustainable Development Goal 12), the Material footprint encompasses all four categories, including Biomass.

Finland's Material footprint is over 7x higher than the global boundary, making it the largest in Europe (Figure 1). The predominant factors contributing to Finland's Material footprint are extensive use of sand and gravel, alongside the country's metal ore extraction rates, which also surpass the European average.

It is worth noting that the environmental impact of material use varies depending on the types of materials used. The Material footprint does not take into consideration the intensity of the environmental impact, e.g., the land-use changes, resource extraction, and biodiversity loss caused by the material extraction and use. For example, while sand and gravel represent a significant share of Finland's Material footprint, the environmental impact per ton used is less than that of fossil energy materials (e.g., oil and gas). Therefore, the Material footprint should be assessed at the material level to identify the impact and potential solutions. Discussion on the underlying drivers can be found below in the resource category deep dives.

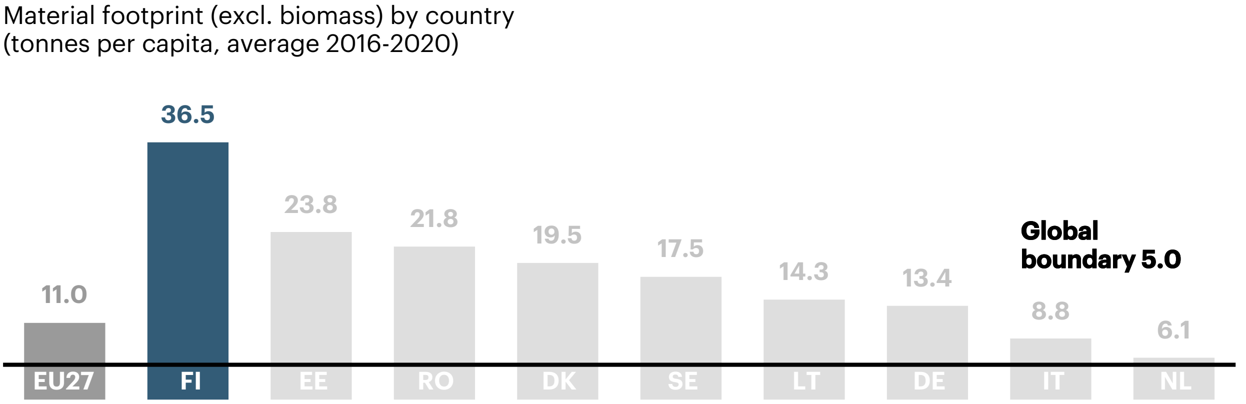


Figure 1: Material footprint (excl. biomass) by country, Raw Material Consumption (RMC)[5,6,7,8]

Finland's Raw Material Flow (DMC)

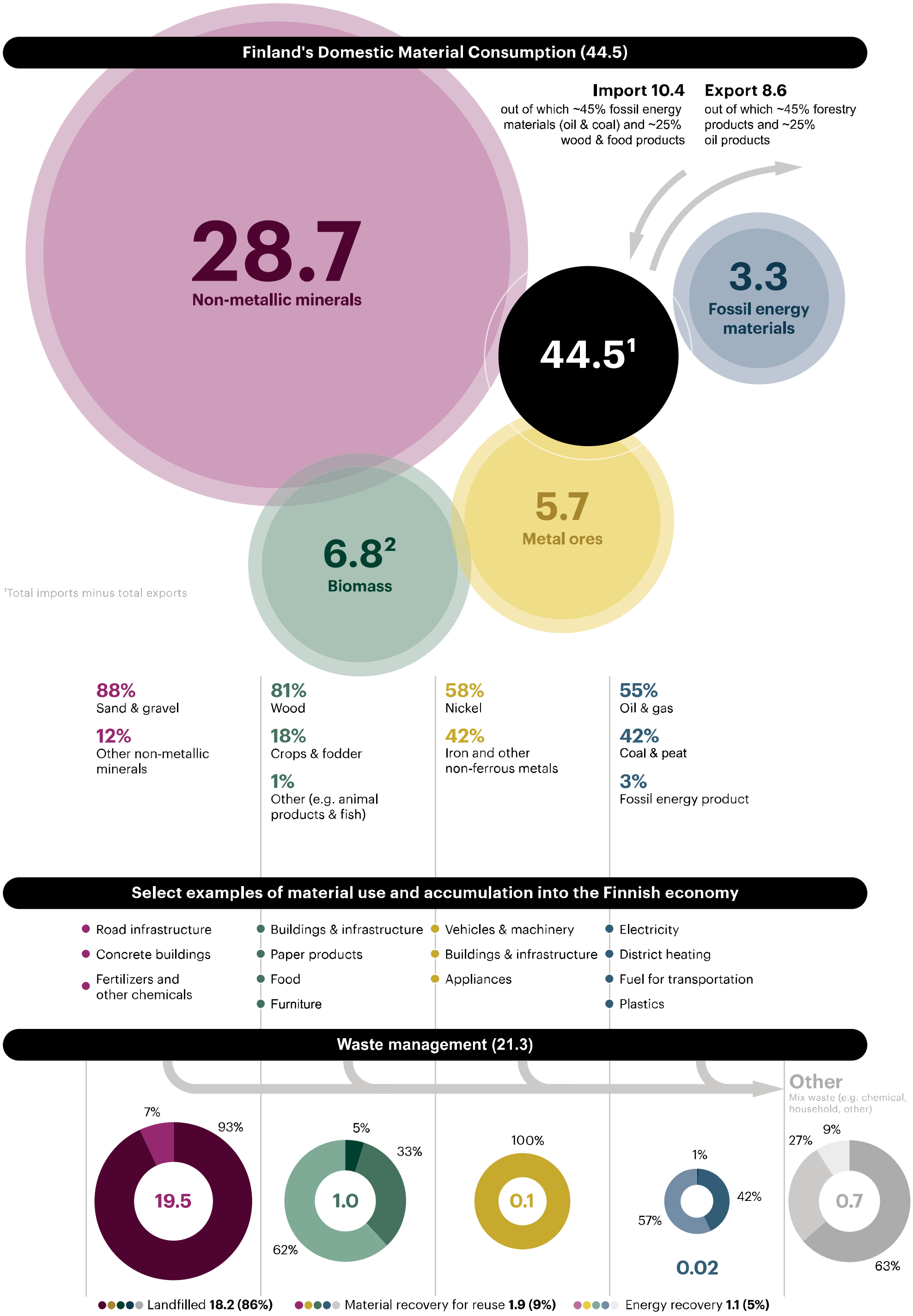


Figure 2: Finland's raw material flow (DMC)

Note: (1) Domestic Material Consumption (DMC) covers material trade but omits upstream supply chain inputs, included in RMC. The gap between DMC and RMC is ~4%. DMC excludes other products totaling 0.2; (2) Biomass footprint of 6.8 includes a deduction of 2.1 due to net export from the category 'products mainly from biomass'; (3) Raw material consumption exceeds waste generation as materials accumulate in society

Finland needs to reduce its raw material consumption significantly to address its large footprint, with improvements in material circularity serving only as an initial step

Finland's excessive Material footprint is associated with overconsumption of material resources, especially sand and gravel and metal ores which have profound negative environmental externalities both domestically and globally. Activities such as construction, along with sand and gravel quarrying and metal ore mining, are major threats to biodiversity. Finnish Red List of endangered species identifies the primary threats to the country's biodiversity, ranking construction on land as the sixth most significant threat, construction of waterways as the ninth, and sand and gravel quarrying as well as mining as the tenth. This combined impact from construction-related activities is more than seven times higher than the impact of climate change.[9] Also the impact of climate change on biodiversity is expected to grow as the planet is getting hotter.

Beyond the habitat disruption and groundwater contamination, the high Material footprint also indirectly accelerates climate change by releasing substantial amounts of greenhouse gases in the material refining and manufacturing processes. This multifaceted environmental degradation underscores the urgent need for Finland to reassess and decrease its Material footprint as a plan to mitigate these negative impacts and to protect the ecosystem services.

> "Circular economy will not be sufficient – a shift in economic paradigms towards dematerialization is needed to bring footprints within global boundaries"

To bring Finland's Material footprint within global sustainability boundaries, a drastic reduction in consumption across all material categories is necessary. The following activities will not fully bridge the gap to sustainability boundaries as that would require significant modifications to the current economic system (discussed in more detail in the final chapter). However, to initiate steps towards the global boundaries within the existing economic framework, Finland could enhance circularity and shift towards more sustainable alternatives. This includes phasing out traditional fossil-based energy in favor of renewable sources, adopting building practices that minimize waste and reduce the use of virgin materials, and transitioning to materials that have a lesser environmental impact.

The construction sector can significantly reduce its reliance on non-metallic minerals (e.g., sand and gravel) by promoting the use of recycled materials, increasing renovation instead of demolitions and new builds, and enhancing the overall circularity within the industry. Additionally, techniques such as increasing the lifespan of buildings, utilizing lighter concrete structures, and integrating timber framing instead of conventional concrete are pivotal. These changes not only decrease the demand for raw material extraction but also aligns with a sustainable development ethos that prioritizes long-term environmental health over short-term gains.

Finland's high metals usage and low circularity rate necessitate aligning the demand of its intensive industrial and construction sectors with environmental objectives. Similar to non-metallic minerals, it is crucial to implement policies that promote responsible mining practices, encourage the use of alternative materials, and enhance recycling efforts.

On the fossil energy material front, continuing to reduce the fossil-based energy is paramount. Finland can further accelerate the progress by providing more substantial economic incentives for renewable energy projects and ensuring that fossil-based energy production is phased out. These efforts are critical in steering Finland away from fossil fuels and towards a sustainable energy model, thereby supporting the nation's overall environmental strategy and its alignment with global sustainability targets.

Finland must commit to an accelerated transition towards circular economy principles, renewable energy, and sustainable industrial practices. While achieving full circularity across material types is a necessary first step in reducing Finland's footprint, it will still be insufficient to bring its footprint within global sustainability boundaries.

Non-Metallic Minerals Footprint: Deep Dive

Sand and gravel is the largest single contributor to Finland's Material footprint and is directly linked to biodiversity loss

The data show that Finland significantly outpaces the rest of Europe in non-metallic mineral consumption (Figure 3), being nearly 50% higher than Romania's which ranks as the second, and almost four times above the EU27 average. Non-metallic mineral consumption is predominately comprised of sand and gravel, with only 12% attributed to other mineral sources like inorganic fertilizer.

Extraction of sand and gravel poses significant risks to biodiversity by degrading natural habitats, polluting water sources, and causing increased erosion that disrupts natural processes. Finnish Red List of endangered species finds that quarrying and mining are the tenth highest threat for Finnish species.

Moreover, resources like sand and gravel are finite and currently being depleted at an accelerated pace worldwide[10]. While sand and gravel use cause less environmental harm per ton than greenhouse gases from fossil energy or excess nitrogen and phosphorus nutrient load, it is still an important measure of the pressures resource extraction and use are causing. Reduction is therefore crucial both for mitigating the environmental damage caused by extraction and for preventing potential future shortages of sand and gravel.

Non-metallic minerals consumption by country
(tonnes per capita, average 2016-2020)

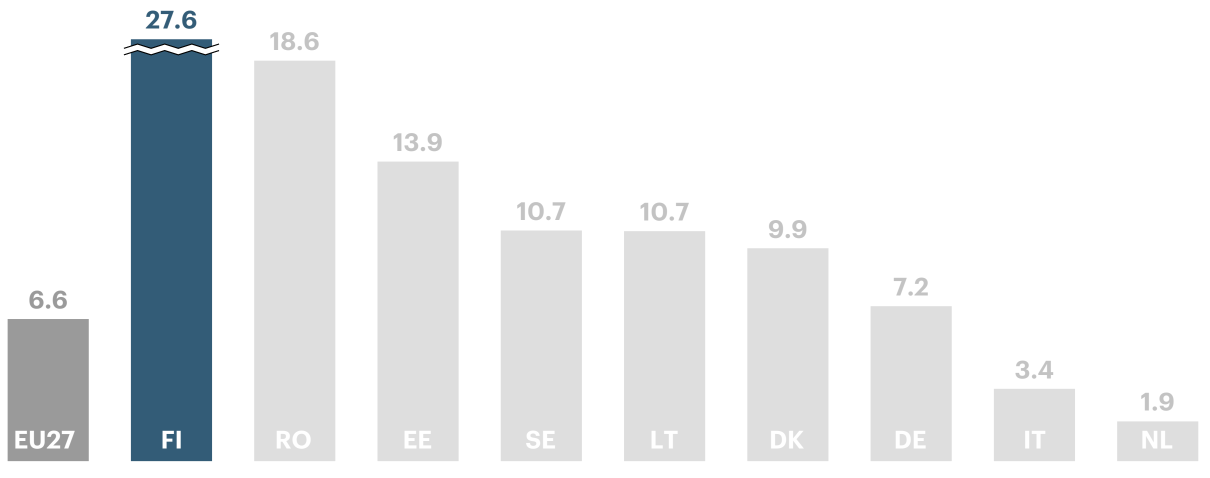


Figure 3: Non-metallic minerals consumption by country (RMC)[11,12,13,14]

Sand and gravel reliance seems linked to construction and infrastructure maintenance

Sand and gravel are key materials in construction and road maintenance[15]. Finland's extensive consumption of these materials seems to be driven by its sizeable construction industry, which represents one of the largest in Europe as a share of GDP[16]. With approximately 80 meters of road per capita[17], Finland boasts one of the most comprehensive road networks globally. This extensive infrastructure, combined with the regular requirement for road resurfacing and repairs owing to the harsh winter conditions, leads to a per capita asphalt usage in Finland that is two to three times higher than the EU average[18].

Metal Ores Footprint: Deep Dive

Finland is the largest per capita consumer of metal ores in Europe, causing considerable environmental impact both from mining and smelting-related greenhouse gases

Finland is the single largest per capita consumer of metal ores in Europe (Figure 4). Notably, Finland's footprint is ~1.4 times higher than Sweden, which is the second highest in Europe.

Finland's high consumption of metal ores presents significant environmental challenges and underscores the need for more sustainable practices. The environmental impacts of the metal usage stem both from mining, which causes biodiversity loss and groundwater contamination (discussed below), and from refining and manufacturing, which generates significant greenhouse gas emissions.

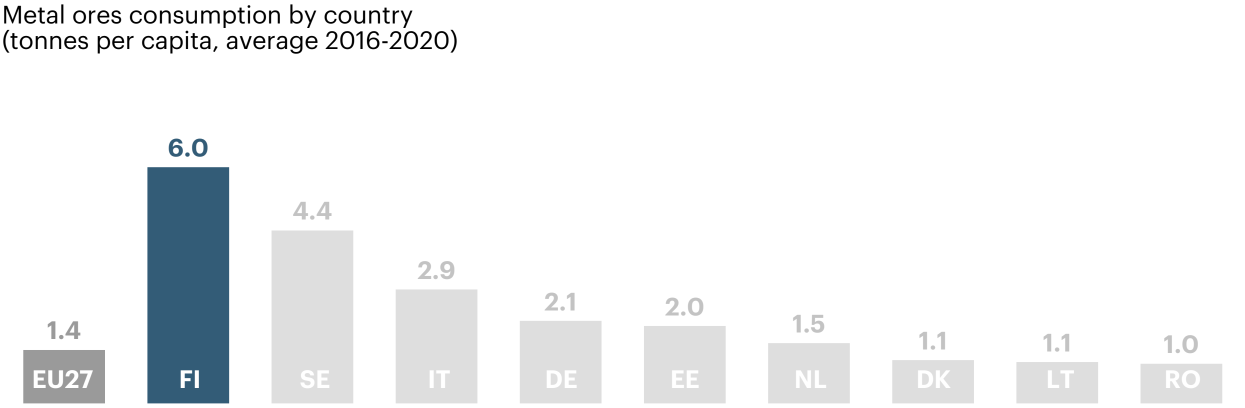


Figure 4: Metal ores consumption by country (RMC)[19,20,21,22]

Finland's extensive metal ore footprint is primarily driven by the high demand of its construction sector, compounded by a low metal circularity use rate

Finland's substantial consumption of metal ores is influenced by several factors. The two key drivers of the high consumption rates seem to be Finland's large construction sector (discussed above in the non-metallic minerals section), and its low rate of material circularity.

In Finland, practically all metal waste gets recycled. This shows that the country has robust systems in place to process its metal waste and feed it back for reuse. However, there seems to be a significantly increasing amount of accumulated metal within Finnish society that is not being recycled and returned to circulation. In 2017, Finland's circular material use rate for metals[1] was only 2%, markedly below the European average of 22%[23], suggesting much higher levels of metal accumulation in Finland compared to the rest of Europe (Figure 5). As an example, a survey by Statistics Finland revealed that nearly all Finnish households are storing old recyclable appliances and items rich in metals[9]. This represents a potential reserve of millions of appliances that could be recycled and reintroduced into the economy's metal material flow. Further research is needed to understand the drivers of the high metal accumulation in Finland, to design targeted policy measures.

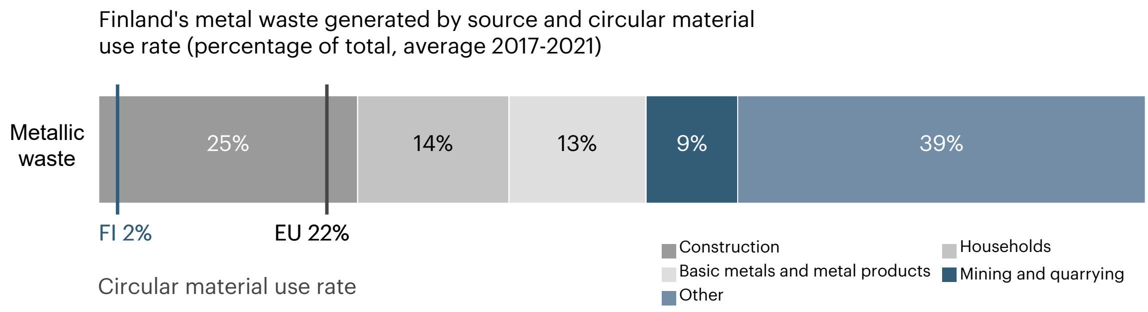


Figure 5: Finland's metallic waste generated by source and circular material use rate in Finland and EU[24,25]

Looking beyond the footprint: Finland's mining and quarrying practices

Fundamentally, all mining activities present significant and distinct risks to biodiversity, underscoring the need for reduced consumption. Mining is particularly harmful in sensitive land areas, such as conservation priority areas, where mining increases habitat destruction and pollution.[26] The increasing demand of various metals and the expansion of mining into increasingly scattered and biodiverse areas call for improvements in mining practices. Furthermore, open-pit mines generate waste at a rate eight to ten times higher than underground mines due to the extensive removal of topsoil, overburden, and other rock.[27] In Finland, while mining is still concentrated – the three largest mines account for 86% of the country's total extraction – but all are operated as open-pit mines.[28] This significantly exacerbates the environmental impact of Finland's metal ore footprint and underscores the need to both reduce virgin material use and to assess current mining practices.

[1] Circular use rate: total metal waste recycled (equaling total metal waste generated) divided by total raw metal ores consumed

"Open-pit mines produce eight to ten times more waste compared to underground mines as a greater amount of topsoil and waste rock must be removed – the top three mines in Finland are open-pit, responsible for 86% of total mining volume"

The majority of Finland's total waste is mineral waste, most of which is ends up in landfills (Figure 6). In Finland, the primary source of the mineral waste is mining waste, accounting for approximately 90 million tons. Mining waste comes from extensive extraction of metal ores and sand and gravel. Notably, the average EU27 circular material use rate for mineral waste is triple that of Finland. This highlights the need for more efficient mining practices and waste management in Finland.

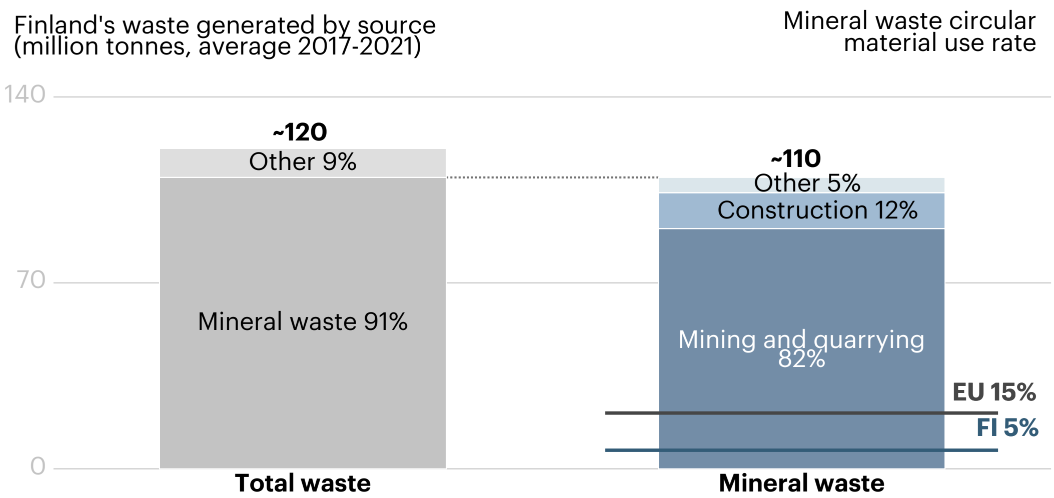


Figure 6: Finland's mineral waste by source and mineral waste circular material use rate[29,30]

Fossil Energy Material Footprint: Deep Dive

Finland has successfully reduced its reliance on fossil energy materials, but there is still room for improvement, particularly in the fields of heat generation and transportation

Fossil fuels are a major driver of climate change, being the largest source of greenhouse gas emissions. This not only poses severe risks to global ecosystems but also impacts economies and communities worldwide.

Finland's use of fossil energy material aligns with the European average but falls behind its neighbour Sweden (Figure 7). The footprint mainly consists of black coal, peat, oil, and natural gas, which are primarily used for generating heat and electricity, as well as fueling transport.

Remarkably, Finland has made significant strides in recent years, reducing its fossil energy material footprint by over 30% since its peak in 2018. Three-quarters of this reduction is due to the country phasing out its use of peat, which has decreased by 80% since 2018. Combined with a continuing decline in the utilization of major fossil fuels like oil and natural gas, this substantial drop signifies Finland's dedicated efforts to transition towards more sustainable energy resources. However, despite these commendable achievements, there remains a critical need for Finland to further decouple especially its district and industrial heating as well as transportation sectors from fossil energy materials.

Fossil energy materials/carriers consumption by country
(tonnes per capita, average 2016-2020)

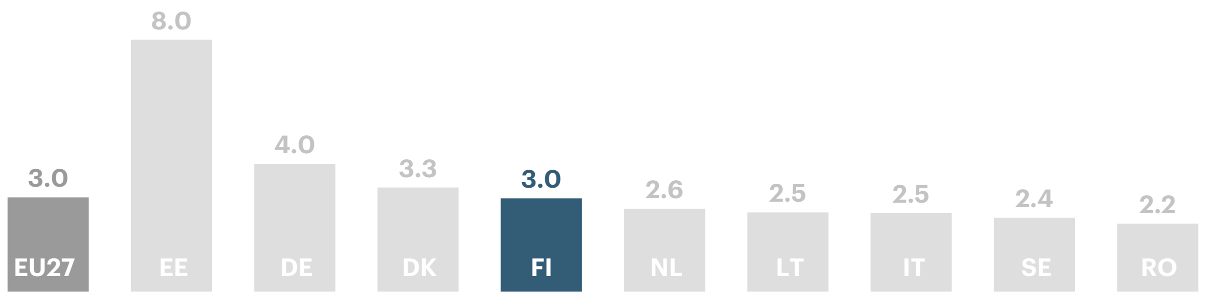


Figure 7: Fossil energy materials/carriers consumption by country (RMC)[31,32,33,34]

Looking beyond the footprint: Finland's plastic recovery and recycling

Finland has taken a significant first step in dealing with its plastic waste by ensuring that nearly all of it is either recovered or incinerated, effectively preventing pollution in natural habitats (Figure 8). However, despite the benefits of incineration over oceanic and terrestrial accumulation, there is growing recognition to increase the circularity of plastic materials in order to reduce dependence on fossil raw materials. Enhancing material recovery and recycling efforts could further diminish Finland's footprint. For example, Lithuania has been able to recycle almost three times more of its plastic packaging waste compared to Finland (Figure 8). This points to a need for Finland to develop a more sustainable approach to plastic waste management by increasing the recycling capture and rate of plastic waste.

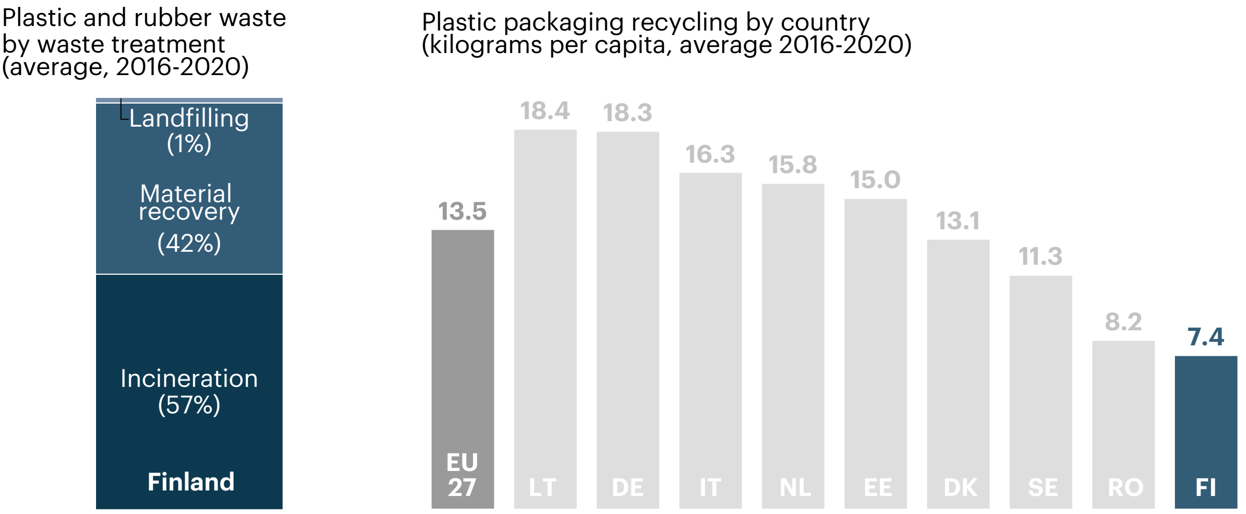


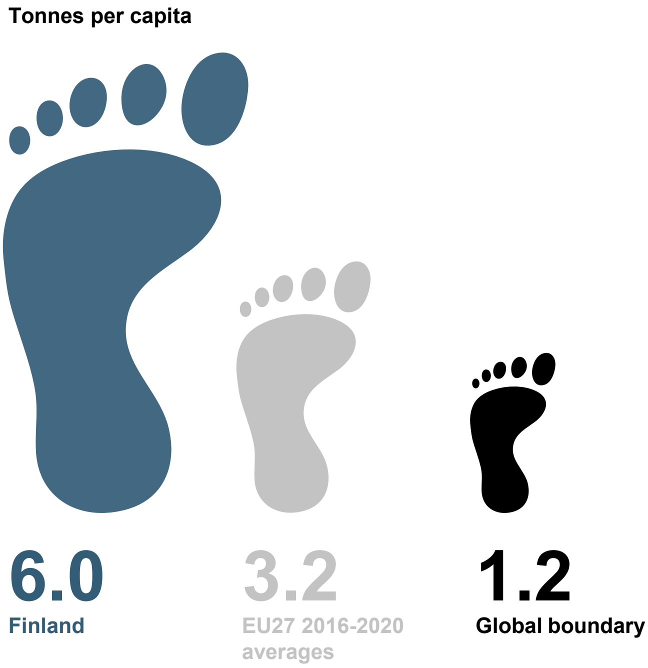
Figure 8: Plastic and rubber waste breakdown by waste management and plastic packaging recycling by country[35,36]

Biomass Footprint

Finland's Biomass footprint is five times the global sustainability boundary

Similar to Material footprint, Biomass footprint includes all non-recycled raw materials used in domestic consumption and excluding exports.

Finland's per capita Biomass footprint is five times higher than the global sustainability boundary and nearly double the European average (Figure 9). This substantial footprint primarily consists of the domestic use of industry byproducts, such as lignin and wood chips, which are mainly used for domestic energy production.



The vast forests of Finland provide more than just resources, they also serve a vital role in protecting biodiversity, sequestering carbon, and supporting other ecosystem services. Therefore, they have a significant environmental impact. Almost 90% of Finland's approximately 23-million-hectare forests are primarily utilized for economic purposes by the forestry sector[37]. These forests have less biodiversity than wild forests due to their lower share of deadwood, loss of old trees, and change in tree species composition from their natural state.[38] Additionally, in the latter half of 20th century, Finland drained nearly five million hectares of wetlands to increase forest land for its forestry sector.[39] As a result from the harvests and forestry practices, more than 70% of Finnish forest habitat types are considered endangered or worse, with approximately 12% of species living in Finland classified as threatened, including Siberian flying squirrel, white-backed woodpecker, and longhorn beetles.[40]

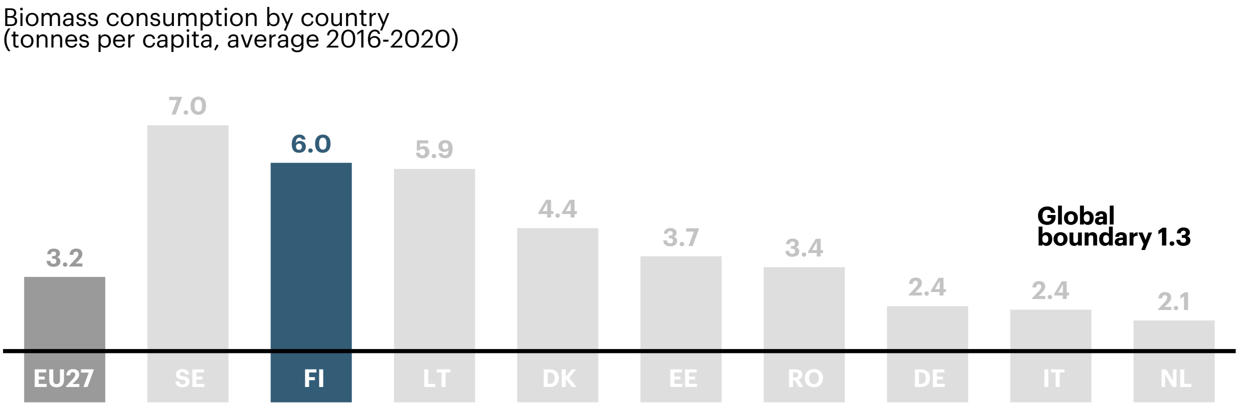


Figure 9: Biomass footprint by country (RMC)[41,42,43,44]

Finland's high Biomass footprint is due to its use of pulp and paper industry byproducts

Biomass footprint in Finland is predominantly comprised of wood products from its large forestry sector and downstream pulp and paper industry (Figure 10). In domestic consumption, the wood products are primarily pulp and paper byproducts like lignin and wood chips, which are mostly used for local heat and electricity production – currently the most economically effective way to reduce production waste at scale. As a result, over 30% of Finland's end-use energy consumption is sourced from dedicated wood for energy use and pulp and paper byproducts, standing out as the highest rate among European and other industrialized nations.[45]

It is important to note that the Biomass footprint measures only domestic use. The main products of Finland's forestry sector are largely exported and therefore not included in Finland's Biomass footprint, but the byproducts of production are not economical to export. Hence, while the Biomass footprint accounts for domestic consumption, it is primarily driven by international demand for Finland's primary wood products and the resulting consumption of byproducts locally.

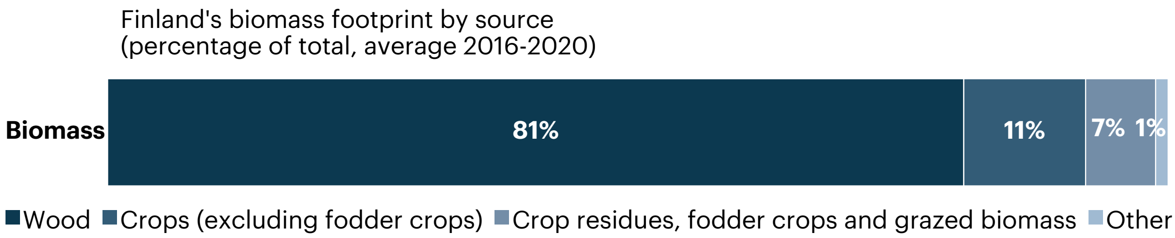


Figure 10: Finland's biomass footprint by source (DMC); Based on domestic material consumption; Other category includes wild fish catch, aquatic plants and animals, hunting and gathering, live animals and animal products[46]

Finland should focus on ecologically sustainable harvest levels, while further investing in alternative uses for wood and its byproducts to leverage its current footprint better

As a country heavily covered by forests, Finland utilizes almost 90% of its forest lands, a factor that presents economic and political complexities when it comes to reducing wood consumption. Moreover, Finland accounts for over 10% of Europe's forest land, indicating its crucial role in the production of wood-based products for European consumers.

Currently, Finland's Biomass footprint substantially surpasses globally sustainable limits. Aligning with the sustainability boundaries would necessitate a significant overhaul of the economic system to reduce the wood inputs, which is discussed in the final chapter. Thus, Finland's strategic focus on its wood use should be to achieve ecologically sustainable harvest levels to ensure the long-term biodiversity health and productivity of its forests.

Beyond ecologically sustainable harvesting and reducing the total biomass wood input, Finland also needs to further invest in and steer its forestry sector to explore alternative uses for wood and its byproducts. This aids in reducing the domestic environmental footprint. In addition, utilizing byproducts more effectively would relieve pressures on other footprints (e.g., fossil energy materials by reduced plastic use) and prove more beneficial than incineration, which emits a considerable amount of CO_2. Given Finland's status as a global leader in the pulp and paper industry, it could shape the broader industry by developing and promoting higher value-add alternative uses for the wood byproducts.

For Finland and its forestry sector, it is crucial to explore new sectors where wood products can serve as sustainable alternatives to environmentally harmful materials like plastics and concrete. This shift has the potential to foster sustainable solutions both domestically and globally. Innovative practices such as deplastification and the development of sustainable uses for biomass byproducts like lignin can enhance environmental outcomes. These practices aim to shift the traditional role of these byproducts from incineration for energy to more sustainable applications, thereby diminishing environmental impacts while potentially improving economic viability.

Ongoing research focuses on commercializing pulp and paper byproducts into innovative products like bioplastics, lignin glues, bio-based concrete, bio-asphalt, and refined lignin for use in lithium-ion batteries, among others. Despite the potential, these alternatives have not yet achieved commercial viability on a large scale, highlighting the need for continued research and supportive policies to encourage diversification in wood byproduct applications. Additionally, leveraging wood and its byproducts in construction and infrastructure to replace traditional materials such as concrete and steel could significantly reduce greenhouse gas emissions.

The second and third most significant contributors to Finland's Biomass footprint are crops and animal fodder. In order to reduce this portion of the Biomass footprint, shifting towards more plant-based diet and reducing food waste is required (discussed in the Ecological footprint).

Finland's path towards reducing its domestic Biomass footprint involves both consumption reductions, but also more efficient use of biomass materials, especially wood. Through innovation in the use of wood products and the investigation of sustainable alternatives, Finland can pave the way for a balanced and sustainable approach to biomass utilization. This would ensure both environmental integrity and potentially reduce Material footprints (e.g., plastic use).

Ecological footprint

Finland's Ecological footprint is over three times the global sustainability boundary

The Ecological footprint illustrates the rate at which we consume resources and produce waste compared to the rate at which nature can generate resources and absorb our waste. This measurement uses the total area of global hectares per capita required for different usage categories, including built-up land, fishing grounds, carbon sequestering land, forest land, grazing land, and cropland. Similar to Material and Biomass footprints, the Ecological footprint includes imports but excludes exports.

Finland's Ecological footprint is measured at a substantial 5.4 global hectares (gHa) per capita, which is over three times the global boundary (Figure 11). This indicates that the average person in Finland consumes and creates waste at a rate that is more than triple what the Earth can sustainably accommodate. In a broader European context, Finland's Ecological footprint slightly exceeds the EU27 average (Figure 11).

While Finland's Ecological footprint is primarily driven by its significant carbon emissions, this chapter focuses on the secondary contributors of forest and cropland, given the extensive analysis of carbon footprint available in other studies.

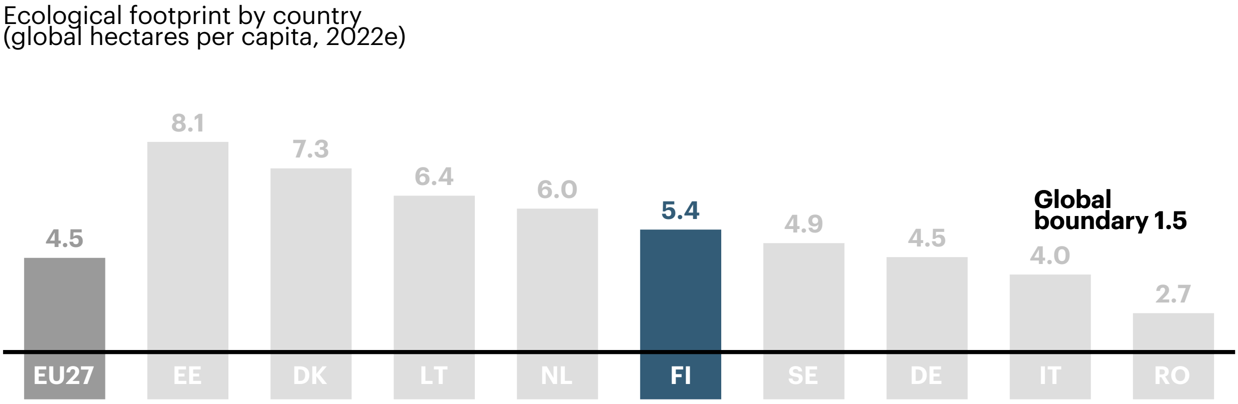


Figure 11: Ecological footprint by country[47]

While this report examines the footprint in isolation, Finland is a net 'ecological creditor', with an excess of biocapacity compared to its footprint

On a domestic level, Finland has a significant amount of excess biocapacity, largely due to its vast forest land (Figure 12). This forest land is a critical component of the worldwide effort to combat climate change, acting as a significant carbon sink that sequesters carbon dioxide, thus reducing the amount of it in the atmosphere. This global asset requires proactive protection and the adoption of forest management practices that prioritize conservation to maintain its high biodiversity value and carbon storage as well as further enhance its effectiveness.

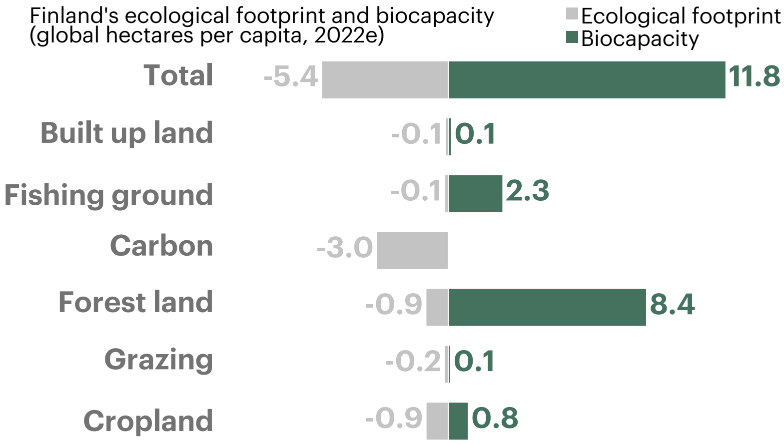


Figure 12: Finland's Ecological footprint and biocapacity[48]

A shift towards plant-based diets and the elimination of food waste could potentially reduce the environmental pressures from agriculture in Finland by half

Meat and dairy production in Finland utilize a considerable proportion of its agricultural land, encompassing both cropland and grazing lands. In fact 70 % of the agricultural land is dedicated to producing animal feed[49].

A shift towards diets with reduced meat and dairy consumption could significantly reduce the demand for cropland dedicated to animal husbandry (Figure 13). Such dietary shifts offer a pathway for Finland to reduce its Ecological and Biomass footprints.

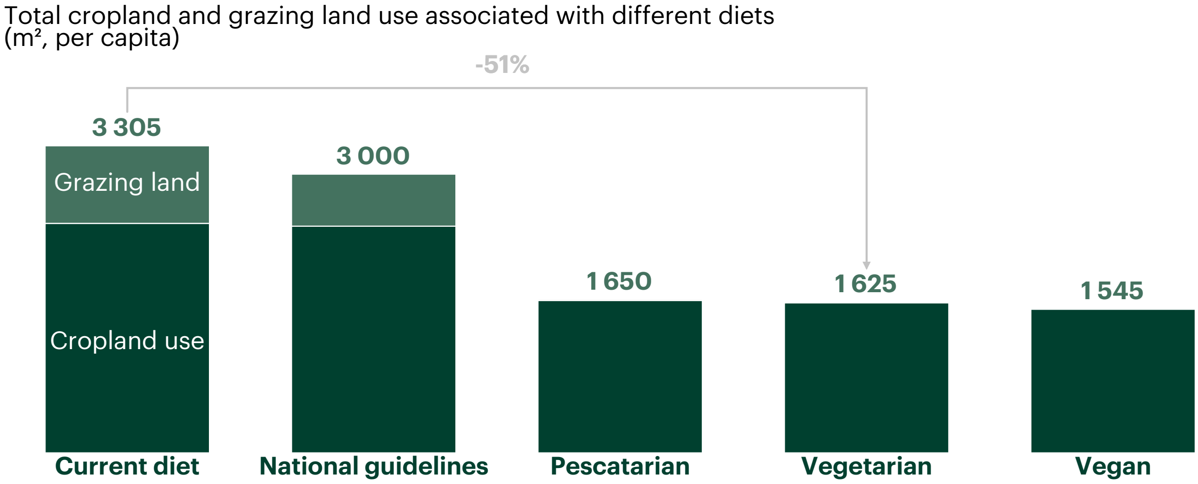


Figure 13: Total cropland and grazing land use associated with different diets in Finland[50]

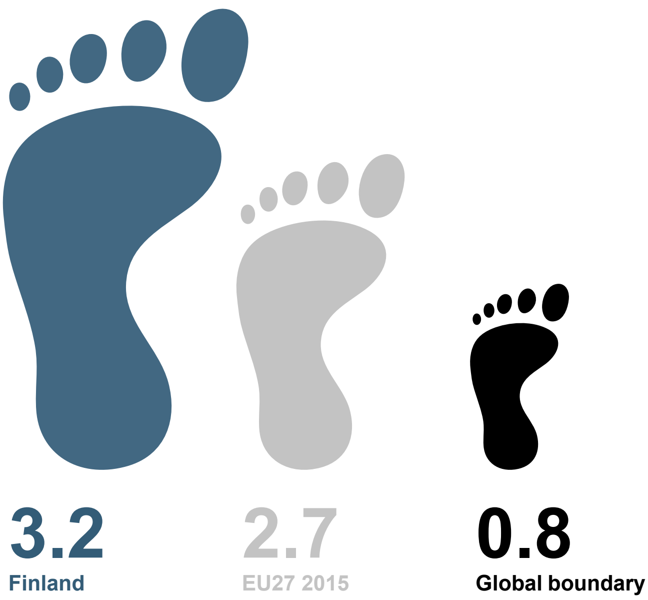
Dietary changes represent an impactful way for everyone to reduce their Ecological footprint. Compared to shifting to plant-based diets, the impact of reducing food waste is moderate, but still an issue to address: In Finland, 10-15% of all edible food produced is wasted, with households accounting for one third of the total food waste[51]. As Finland has pledged to halve its food waste by 2030, effective stock management in grocery stores and streamlining industrial processes in the food industry should be implemented.[52]

Nitrogen and Phosphorus Footprints

Phosphorus Footprint: Deep Dive

Finland's Phosphorus footprint is four times the global sustainability boundary

The Phosphorus footprint refers to the total quantity of phosphorus from inorganic fertilizers used in a country, underscoring the overall environmental impact relative to the nation's size. This does not account for factors such as crop import and export or the use of organic fertilizers like manure. This footprint acts as an indirect indicator of both the current and future environmental impacts of agriculture, given the soil's nutrient storage and delayed release of nutrient load.



Finland's footprint exceeds the European average and is four times higher than the global boundary[53] (Figure 14). However, this figure likely underestimates the actual footprint since it only considers synthetic fertilizers and excludes manure and other inputs. Phosphorus balance would provide a more precise reflection of phosphorus usage effectiveness, as it accounts for both inputs and outputs, such as phosphorus removal through harvested crops and fodder. Due to the lack of time series data on phosphorus balance for peer countries, a production-based allocation method is utilized.

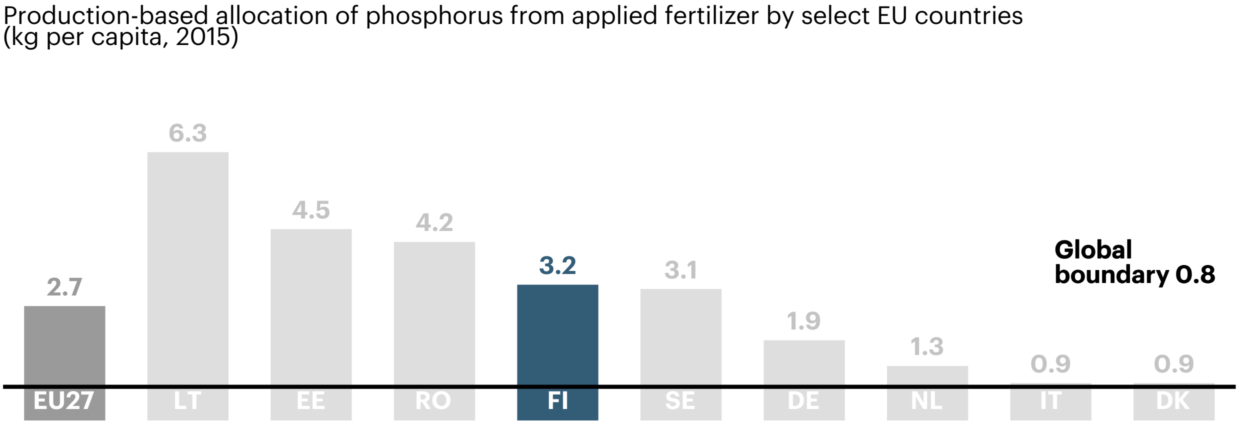


Figure 14: Production-based allocation of phosphorus from applied fertilizer by selected European countries measured in kg per capita[54]

Applied phosphorus per hectare shows Finland's Phosphorus footprint to be well below the European average and better than most peer countries

Since the size of a country's agricultural sector significantly influences its per capita footprint, the per hectare footprint gives a more accurate view of synthetic fertilizer application in a country (Figure 15). Finland's per hectare footprint is below the European average, suggesting that while the per capita phosphorus load is high, the efficiency of phosphorus remains high compared to the EU27 average.[55,56]

However, comparing Finland to countries with similar agricultural conditions, soil types, and climate, Denmark proves to be more efficient in its phosphorus utilization. Through targeted phosphorus policy measures, Denmark has achieved a 54% reduction in phosphorus usage from 1995 to 2015, while Finland experienced only a 9% decrease[57]. This disparity highlights a significant opportunity for Finland to draw on Denmark's successful strategies to manage and reduce its own Phosphorus footprint more efficiently.

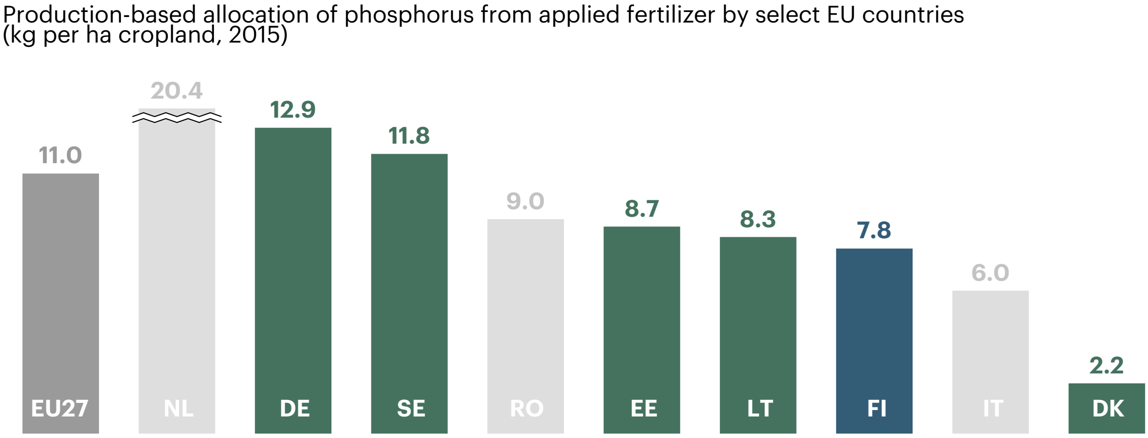
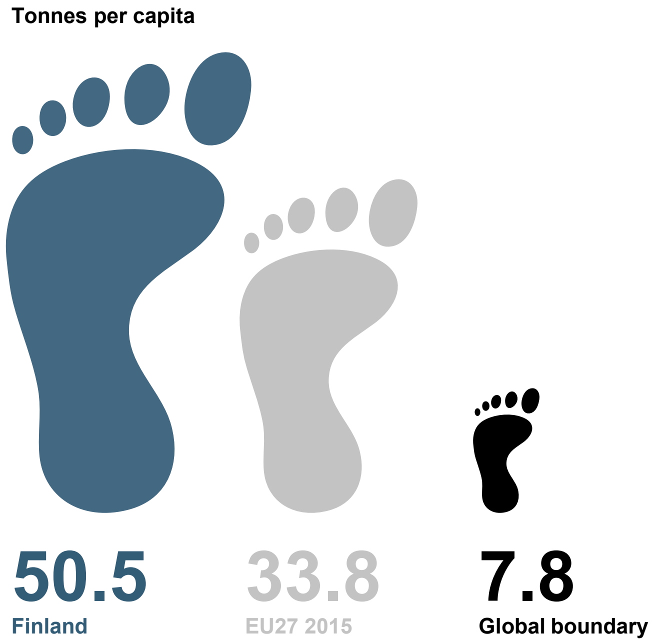


Figure 15: Production-based allocation of phosphorus from applied fertilizer by selected European countries in kg per hectare of cropland[58]

Nitrogen Footprint: Deep Dive

Finland's Nitrogen footprint is over six times the global sustainability boundary

Similar to the Phosphorus, the Nitrogen footprint refers to the total quantity of nitrogen from inorganic fertilizers used in a country. The footprint does not account for factors such as crop import and export or the use of organic fertilizers like manure. Unlike phosphorus, nitrogen has a lower share of soil storage and consequent load.[59] Therefore, the Nitrogen footprint reflects a more direct impact on the environment.



Nitrogen footprint in Finland (Figure 16) substantially exceeds the European average and the global boundary.[60] In addition, this figure likely underestimates the actual footprint, since it only considers synthetic fertilizers. The Nitrogen footprint fares relatively worse compared to phosphorus, likely because nitrogen is more susceptible to leaching and can enter water systems through various pathways, often at a faster rate than phosphorus. Similar to the phosphorus balance, nitrogen balance would give a more accurate view of the usage effectiveness.

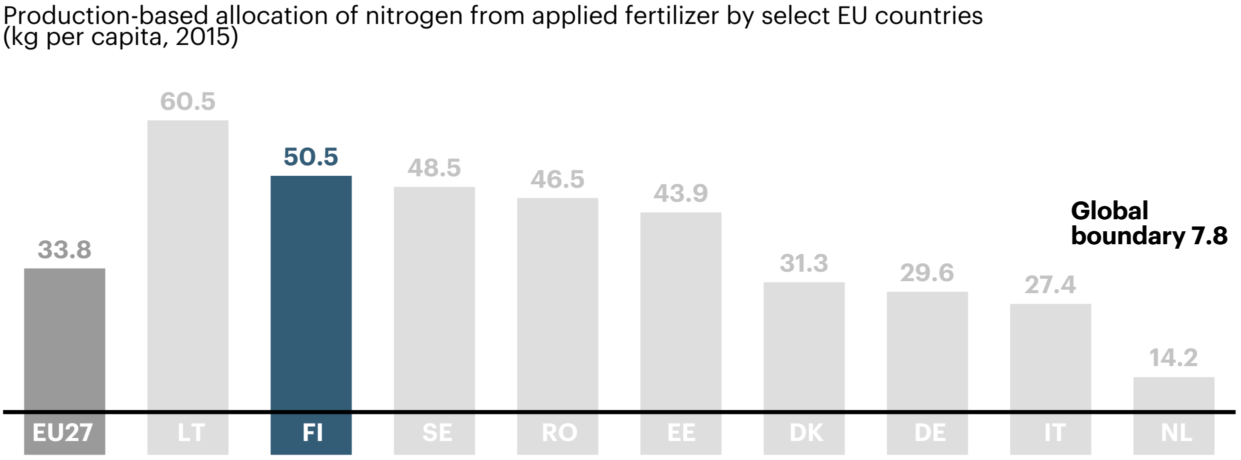


Figure 16: Production-based allocation of nitrogen from applied fertilizer by selected European countries in kg per capita[61]

Applied nitrogen per hectare cropland shows Finland's footprint to be well below the European average and in line with peer countries

Finland's Nitrogen footprint on a per hectare basis (Figure 17) shows high efficiency in nitrogen use in the European context[62]. However, compared to countries with similar nitrogen consumption, Denmark, which has similar agricultural conditions to Finland, uses nitrogen more efficiently. Through effective nutrient policy initiatives, Denmark managed to reduce its nitrogen as well as phosphorus loads by around 55% from 1995 to 2005. During the same period, Finland, on the other hand, only managed to reduce its nitrogen and phosphorus loads by 9%. [63,64] This comparison serves as both an example of what can be achieved through targeted policy changes and improved practices, and as an inspiration for Finland to consider similar actions.

Production-based allocation of nitrogen from applied fertilizer by select EU countries
(kg per ha cropland, 2015)

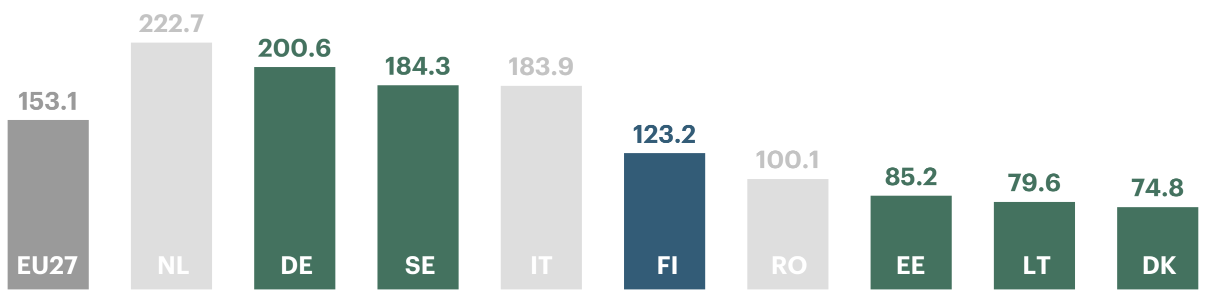


Figure 17: Production-based allocation of nitrogen from applied fertilizer by selected European countries in kg per hectare[65]

Looking beyond the footprint metrics: Finland's nutrient load to the Baltic Sea

Finland generates 13% of the total nitrogen and phosphorus loads going into the Baltic Sea[66]. Most of this load originates from agricultural activities such as fertilizer and manure application which account for 69% of the phosphorus and 54% of the nitrogen. Nitrogen footprint is partly influenced by immediate run-off from fields, though this account for only a minor part of the total runoff for phosphorus. Therefore, reducing phosphorus fertilizers in the short-term would only have a minor impact on eutrophication. However, over time as the levels of 'legacy phosphorus' in the sediment decreases, this will make a significant positive impact. Given such significant contribution from agriculture, any environmental policy aiming to reduce the Baltic Sea's nutrient load must focus on agricultural practices. The key routes through which phosphorus and nitrogen enter the Baltic Sea are illustrated in Figures 18 and 19.

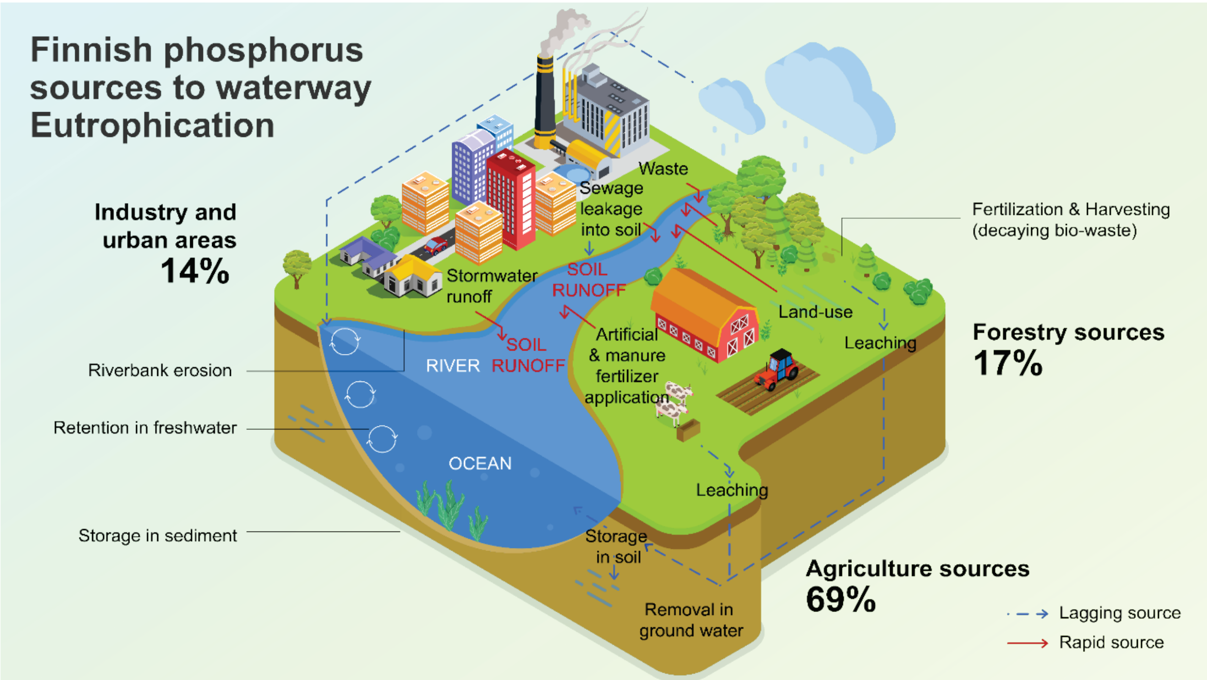


Figure 18: Finland's phosphorus sources to waterway

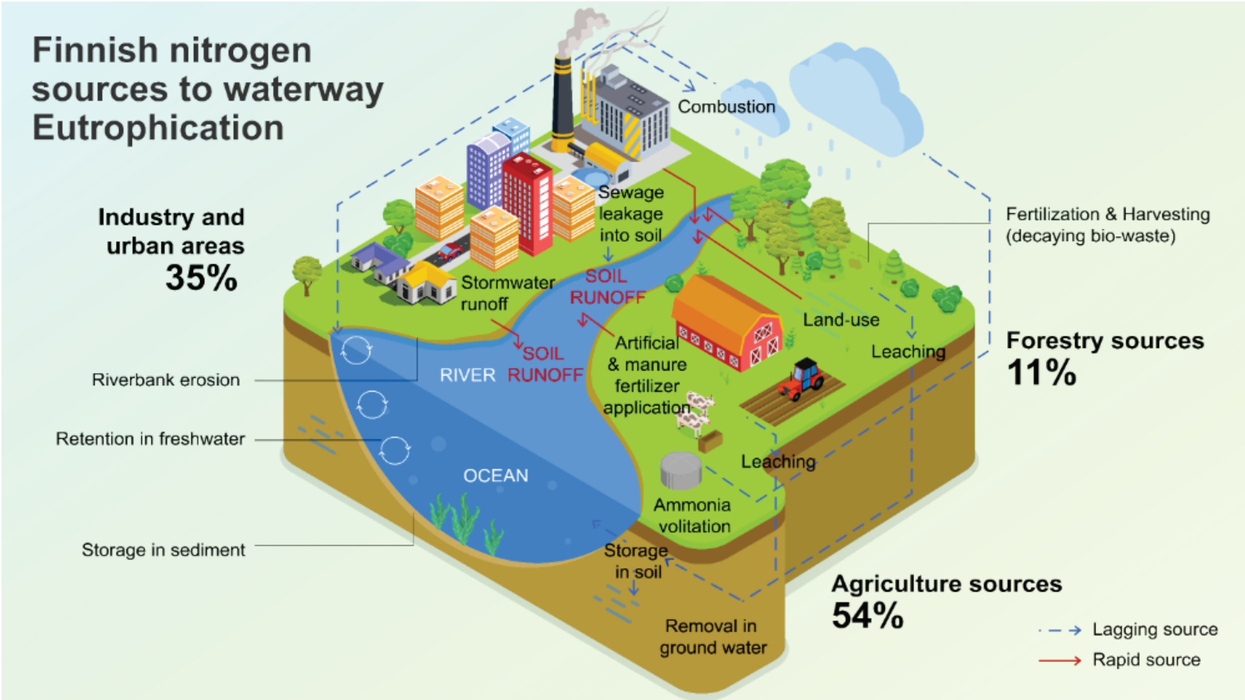


Figure 19: Finland's nitrogen sources to waterway

Nutrient release into the Baltic Sea has led to eutrophication and marine dead zones

The Baltic Sea is currently grappling with an acute environmental crisis predominantly caused by an excessive accumulation of nutrients, especially phosphorus and nitrogen (Figure 20). These nutrients have caused eutrophication, which threatens the sea's ecological balance. Alarmingly, the Baltic Sea contains seven of the world's ten largest marine dead zones[67].

One of the most notable impacts of nutrient over-enrichment is the widespread growth of algae, which can be seen as algae blooms on the water surface. As the algae proliferates, large amounts of oxygen are consumed leading to hypoxic (i.e., ow oxygen) and anoxic (i.e., no oxygen) conditions. Initially, this harms the sea's biodiversity, as many species cannot survive in low oxygen environments. As oxygen levels continue to decrease and the sea becomes anoxic, dead zones are created where only certain specialized bacteria can survive in the deep waters[68].

"The Baltic Sea contains seven of the world's ten largest marine dead zones"

In 2020, a staggering ~95% of the Baltic Sea's surface was impacted by eutrophication and subsequent algae blooms[69]. These blooms not only disrupt the marine ecosystem but also render the water unfit for human activities such as swimming, thereby significantly decreasing the recreational value of these waters.

Furthermore, the imbalance caused by eutrophication impacts the biodiversity in the Baltic Sea. While the total amount of fish increases due to the availability of more nutrients, the variety within the fish communities decreases[70]. For example, fish families like Coregonus (e.g., Common whitefish) and Percidae (e.g., European Perch), both sensitive to changes in water quality and oxygen levels, struggle to survive under eutrophic conditions. On the other hand, species in the Cyprinidae family (e.g., Common Bream), which can tolerate lower oxygen levels and nutrient-rich waters, tend to thrive.

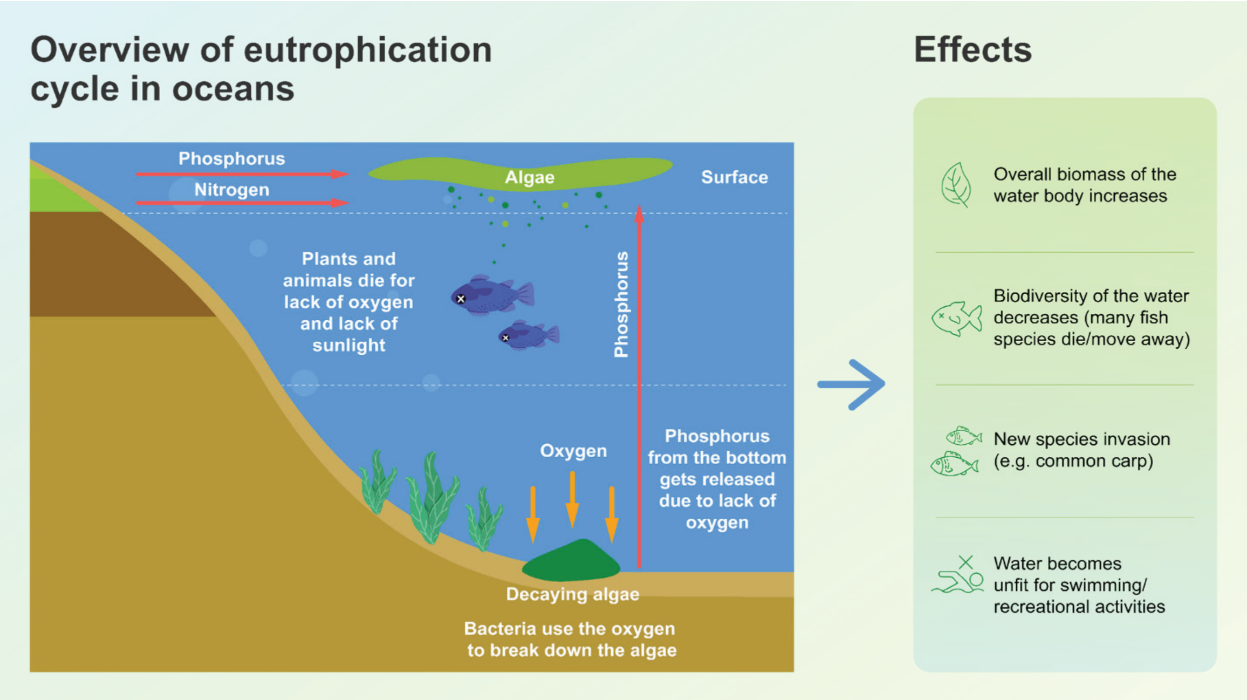


Figure 20: Eutrophication process

Solutions to marine eutrophication require a long-term approach

Despite efforts to improve conditions, the environmental health of the Baltic Sea is deteriorating. Between 2011 and 2016, all metrics indicated a decline in environmental health across all Finnish water areas[71]. One reason for the minimal improvement in the Baltic Sea is the delayed release profile from nutrient-saturated soils, which release phosphorus for over a 30-year period. Given this dynamic, a significant amount of the phosphorus load into the Baltic Sea comes from old 'legacy' sources (Figure 21). Approximately 45% of the phosphorus reaching the Baltic Sea today originates from these legacy sources[72].

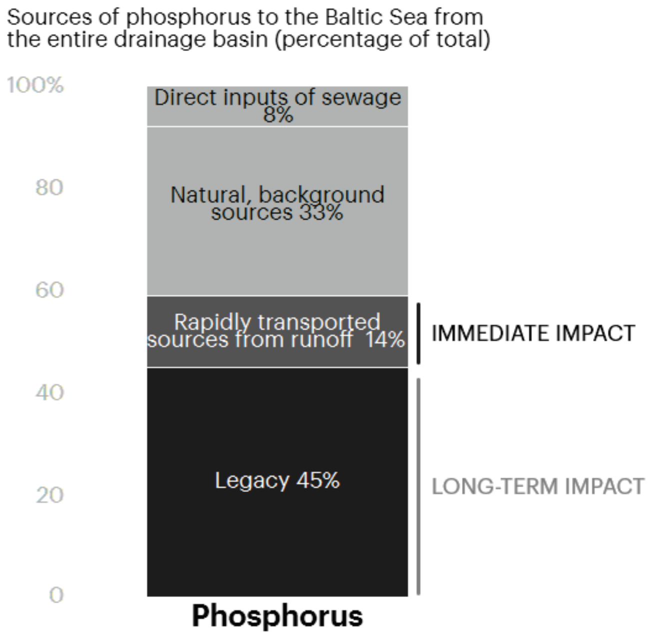


Figure 21: Sources of phosphorus to the Baltic Sea from entire drainage basin

For nitrogen, the residence time is only 1.4 years. Therefore, all agricultural nitrogen ending up in the Baltic Sea comes from recent application of fertilizers[73]. Given the short term and long-term impacts, the recovery of the Baltic Sea would need immediate, sustained, and strategic efforts.[74]

Solutions to improve the condition of the Baltic Sea include reducing animal-product consumption, which would lower the fertilizers usage in animal-feed production. Additionally, implementing targeted policy measures, such as stricter limitations on nutrient use and loads, can further protect the Baltic Sea.

HELCOM

The Baltic Marine Environment Protection Commission (HELCOM) is an intergovernmental organization and a regional sea convention based in the Baltic Sea area. HELCOM's Baltic Sea Action Plan (BSAP) is a strategic program focused on restoring the health of the sea through various measures and actions. The BSAP sets environmental targets that countries must strive to achieve to promote a good environmental status of the Baltic Sea. The current BSAP targets are set for 2030. However, the commission continuously evaluates and adjusts the targets based on the condition of the Baltic Sea, ensuring that the sea's healthy state is obtained. [75]

Table 1 outlines three scenarios that predict the state of the Baltic Sea by 2100. These predictions rely on the commitment of the countries involved in the BSAP.[76]

Scenario	Explanation	Primary production (e.g., algae)	Oxygen deprived bottom environments
Baltic Sea Action Plan (BSAP)	The supply of N and P is continuously adjusted towards to the levels of the HELCOM BSAP	44-40% reduction	49-56% reduction
Reference scenario	No further measures are taken to reduce emissions	0-13% reduction	5-14% reduction
Worst case scenario	Nutrient supply steadily increases and is further strengthened by climate change	2-20% increase	2% reduction to 5% increase

Table 1 Baltic Sea Scenarios[77]

Based on the scenarios, only the BSAP scenario presents significant long-term improvements in the condition of the Baltic Sea. Without additional measures, improvements will only be minimal. Finland has already met the targets for reducing nitrogen input in all its sea areas, and it has also met the phosphorus input targets in two regions: the Bothnian Bay and in Baltic Proper. However, in the Gulf of Finland and, to a lesser extent, in the Bothnian Sea, Finland has not been able to reduce phosphorus to the target levels. In particular, intensive environmental measures need to be employed in the Gulf of Finland, where less than half of the phosphorus reduction has been achieved, indicating the need for more focused and strict environmental measures. This mixed picture underlines the importance of sustained and strategic efforts in underperforming areas to ensure comprehensive achievement of BSAP targets across all regions.[78]

Pathways for Finland’s footprint reduction

The primary factor contributing to Finland’s high environmental footprint is the excessive consumption of physical resources

Finland’s excessively high footprint stems from overconsumption of physical resources, evident when comparing it to global sustainability boundaries and European peers. Finland’s resource consumption far exceeds our planet's ability to replenish, leading to the depletion of natural assets and long-term harm to human well-being. It is crucial to raise awareness and address this issue collectively. Public perception must increasingly view resource depletion as urgent and significant as greenhouse gas emissions, which are linked to climate change. The issue of overconsumption must be integrated into daily decisions and actions at both national and individual levels.

Economist Partha Dasgupta's analyses show that our current economic structure has systematically failed to consider environmental costs, particularly the loss of biodiversity.[79] Within the Finnish context, these findings underscore the need for urgent transformative change to ensure that future economic development and consumption stay within global sustainability boundaries. We need to reevaluate the fundamental principles of economic development and societal well-being, not just policy reform.

An example of this is how Finland manages its forests. Finland is often referred to as a "forest nation" due to its significant economic, cultural, and ecological ties to its vast forests. The forestry sector is a vital part of Finland's economy, supporting exports, jobs, and rural development. However, the forestry sector relies entirely on the ecosystem services provided by forests, but current practices are degrading these services and reducing their ecological budgets. Traditional forestry practices, such as periodic cover silviculture and ditching of wetlands, have caused biodiversity loss, old-growth forest decline, and impacts on ecosystem services.[80]

The inertia of Finland’s current economic well-being and overconsumption is multifaceted. Cultural norms, demographic factors, economic incentives, vested interests, and entrenched thinking patterns all contribute to the resistance against change and embed environmental costs in current economic frameworks. There is a complex interplay among these factors where cultural values may impact consumption habits, demographics shape resource demands, and economic incentives can either promote or discourage sustainable practices. Vested interests also play a role in maintaining the status quo. Undoing this lock-in requires collective effort from government, industry, and individuals to redefine well-being and progress in a world with limited resources. Transitioning to a sustainable economic system poses challenges and costs, as it goes beyond our current experience. Moreover, most existing business models are not suitable for this new paradigm, requiring innovative models designed to operate within planetary limits.

National and EU-level policies are essential for driving transformational change in a fair and just manner

While individual actions can help reduce a person's environmental impact and create a demand for sustainable alternatives, significantly reducing Finland's overall footprint will require governmental action. This entails implementing systemic policy changes to reorient economic incentives towards valuing nature's contributions in market pricing. Additionally, policies should be crafted to encourage early adopters, who can lead by example and demonstrate the viability of sustainable practices. To achieve widespread societal change, it is crucial to support and scale up proven sustainable practices ('backing the winners') while addressing aspects of consumption and production that continue to harm the environment ('laggards'). One example of this multifaceted policy approach is the adoption of renewable energies, such as wind and solar power. The successful expansion and acceleration of this green transition have been facilitated by promoting winners and strict regulations on reducing fossil fuel usage among laggards. This demonstrates that change is possible with strong commitment and widespread societal endorsement.

While national and international policies drive transformational change, private enterprises and individuals also contribute significantly. This is particularly important for businesses with older and more traditional business models. By embracing sustainable practices and reducing harmful consumption, businesses and consumers can drive broader change, creating market demand that influences further policy action and encourages hesitant parties to follow suit.

Proof of concepts are critical in this process. Regulations and transformative policies are more readily accepted and implemented when there is tangible evidence of their effectiveness. Benchmark countries or successful pilot programs demonstrate the positive impacts of new policies and practices, paving the way for scalable implementations. Once proven successful on a smaller scale, regulatory frameworks can be developed to expand these practices, pushing less sustainable players towards more environmentally friendly operations or out of the market. This coordinated effort between voluntary adoption, proof of success, and regulatory enforcement can guide Finland towards a future that aligns with our planet's regenerative capacity.

Direct consumption limits are the most direct way to reduce overconsumption, but must be carefully designed to prevent production leakage

Imposing direct limitations is the most straightforward method to curtail resource overconsumption. However, these measures must be meticulously crafted and coordinated to prevent unintended outcomes such as leakage, where production might simply shift to regions with laxer regulations. To avoid this and ensure Finland takes responsibility for biodiversity loss linked to its consumption globally, it is essential to establish mechanisms that control cross-border trade and promote international cooperation.

Various regulatory options are available for Finland to decrease its environmental footprint within global sustainability boundaries. To achieve this, three policy approaches stand out: (1) curbing overconsumption by factoring in environmental costs, (2) promoting circularity to diminish dependence on non-recycled materials, and (3) ensuring a fair and just transition.

Three potential pathways to further investigate in order to reduce Finland's footprint within global sustainability boundaries

1. Cost-in environmental impact of material use

Design measures to reduce the use of materials like sand and gravel by enacting regulatory measures that limit consumption and promote increased circularity through mechanisms like cap-and-trade schemes

DESIGN EU ETS CONCEPT FOR MATERIALS

2. Improvements on material circularity

Improve recycling infrastructure, promote the use of recycled materials (e.g., with subsidies), and increase returns at recycling points (e.g., with promotions and subsidies) to reduce the inefficient accumulation of materials in society

FURTHER DEVELOP BEST PRACTICES FROM NETHERLANDS

3. Fair and just transition

Design and implement policies that equitably distribute the costs and benefits of environmental actions. Create opportunities for inclusive decision-making, provide retraining and education for workers in transitioning industries, and offer subsidies to support those who are most affected.

Table 2: Potential transformational policy approaches

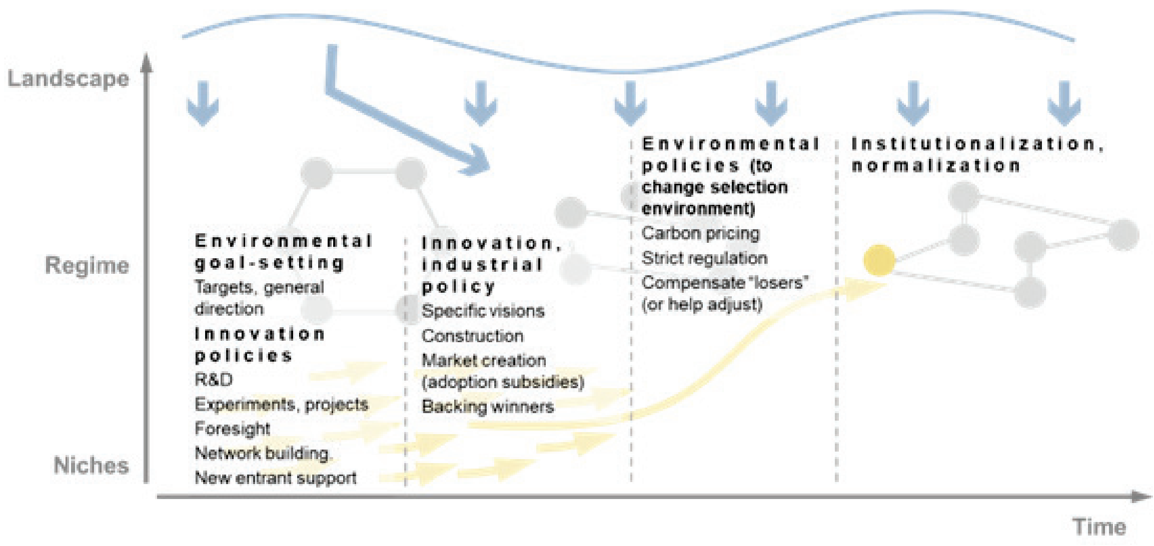


Figure 22: The multi-level perspective on sustainability transitions based on Geels (2002)[81]

Cost-in environmental impact of material use: Adopting market-based mechanisms, like the EU's Emission Trade System (ETS) cap-and-trade scheme for reducing CO_2 emissions, underscores a strategic shift towards pricing environmental impacts and incentivizing for less consumption.

Certain materials, such as sand and gravel, could benefit from similar schemes to effectively reduce overconsumption and bring Finland's footprint within global sustainability boundaries. Such policies require meticulous crafting to achieve their goals and may necessitate coordination at the EU level to prevent production leakages. Additionally, there are limited examples of cap-and-trade schemes beyond reducing CO_2 emissions. However, these types of policies are very powerful in reducing footprints as consumption limits are established prior to policy implementation. In terms of change, Finland is currently in the early stages of awareness without any clear 'Environmental goal setting' or ambitions communicated by the government (Figure 22).

Improvements on material circularity: Transitioning further towards circularity involves improving the recycling and reuse of materials such as sand and gravel, metals, and plastics. Adopting and implementing initiatives and policies from forerunner countries in circularity like the Netherlands could help Finland reduce its Material footprint.

Currently, Finland has established high-level goals for certain materials, but a substantial expansion of these goals is necessary to cover more materials and to turn them into concrete policy actions. Finland needs to implement concrete 'Environmental policies' (Figure 22). An example could be limiting or even stopping building demolitions, instead, focusing on renovation and reusing materials. Another option is subsidizing reused materials over new ones and encouraging more efficient material circulation. This approach would require investment in additional recycling infrastructure and initiatives to motivate both individuals and businesses to return unused material to recycling points. These measures can extend the lifespan of materials and ensure their value is retained, reducing waste, and fostering a sustainable economic model.

Moreover, regulations that incentivize sustainable alternatives can be used to encourage sustainable alternatives, such as subsidies for eco-friendly products and research and development, along with policies that enhance circularity. These are designed to guide consumer and corporate behavior towards sustainability, with the ripple effect of increasing sustainable choices and lessening dependence on environmentally harmful goods and services. However, these measures typically result in slower reductions in overall consumption levels.

Fair and just transition: Ensuring a fair and just transition towards sustainable alternatives and footprint reduction is critical. It underscores the need for policies that equitably distribute the costs and benefits of environmental actions, preventing marginalization of those most burdened by the transition. This is particularly crucial as wealthier households tend to have higher environmental footprints, while the transition poses greater challenges for lower-income households who may lack the resources to adapt easily. It is vital to create opportunities for inclusive decision-making, provide retraining and education for workers in transitioning industries, and offer subsidies to support those who are most affected. This approach accelerates change, boosts resilience, and promotes inclusivity in sustainability efforts, safeguarding those least equipped to handle the transition's costs.

> “Ambitious targets stimulate investments in sustainable technologies and practices”

Furthermore, as Finland has committed to meeting the HELCOM targets for reducing phosphorus and nitrogen runoff into the Baltic Sea, stricter limitations on nutrient use and loads are needed. Though Finland has made progress, further reductions in phosphorous run-offs are urgently needed, particularly in the Bothnian Sea and the Gulf of Finland. Finland has implemented specific policies and aims to meet the targets, such as those set by HELCOM. Still, these measures are inadequate, highlighting the need to move from ‘Environmental policies’ towards ‘Institutionalization, normalization’ (Figure 22).

To achieve further reductions, Finland could emulate Denmark, which has significantly reduced nitrogen and phosphorus run-offs – almost 50 p.p. more than Finland – since 1995. Denmark's successful reduction is attributed to stringent fertilizer limitations, extensive wetland restoration, and better enforcement of land use practices such as catch-crops and buffer zones that limit runoff.

Positively, these actions have had little impact on overall crop yields. These policies and initiatives aiming to significantly mitigate nutrient runoff in Denmark show that environmental impacts can be lessened while maintaining crop yields through targeted action. Finland can adopt similar strategies to decrease its footprint and fulfill its obligations.

The three proven policy approaches from other countries and sectors showcase a shift towards utilizing innovative methodologies that support well-being with significantly lower environmental impact. Incorporating sustainable global boundaries into the development strategies of Finland and the EU provides policymakers with the power to harmonize economic well-being and environmental preservation. Such clear, ambitious targets convey decisive signals to the market, setting clear consumption level expectations. This stimulates investment in new sustainable technologies and practices, ensuring a similar or improved quality of life within Earth's ecological limitations.

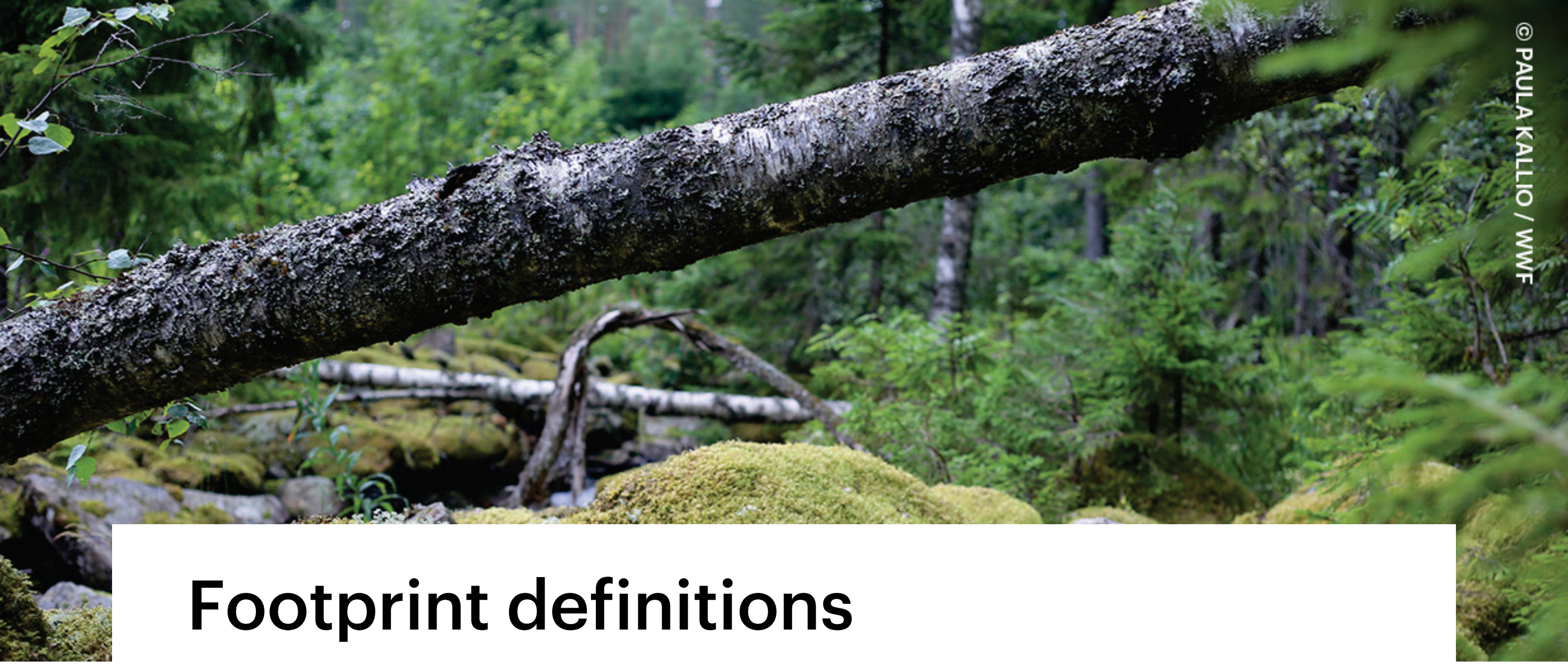
EU and national level policies are most critical, but the involvement of individuals and businesses is also needed to reduce Finland’s footprint within global sustainability boundaries

Individual actions and business innovations are crucial for steering Finland towards sustainability. By consciously reducing material use, each person and enterprise can contribute to diminishing the excessive environmental impact on ecosystems, drawing inspiration from successful foreign practices like the Netherlands’ circularity efforts. Both individuals and businesses can adopt and promote sustainable alternatives, reducing their impact on nature. This collective shift towards a more sustainable lifestyle and operational model is urgent.

The cost of inaction escalates not only the environmental risk, but also the financial burden of future remedies. Early adopters are crucial and must be supported, as they set trends towards general adoption of sustainable practices.

Finland’s journey towards reducing its footprint within global sustainability boundaries should be considerably strengthened with the three key policy approaches mentioned above (Table 2). These strategies target significantly reducing Finland's Nitrogen, Phosphorous, Material, and Ecological footprints, aligning us closer with global sustainability boundaries. Finland can benefit from the pioneering strategies of other nations, including Denmark's nutrient management, the Netherlands' circular economy models, and the EU's emission reduction scheme.

Delaying these essential shifts not only increases the cost of change but also risks the long-term viability of Finland’s natural resources and ecosystems. Decisive action is needed now. Finland must adopt both individual initiatives and systemic reforms to pursue a much more sustainable path. This will ensure a prosperous future for the nation and its natural resources within the planet's ecological limits.



Footprint definitions

To halt nature and biodiversity loss and to ensure a safe operating space for human societies, it's crucial to address the footprint of human activities. A footprint refers to the impact of extraction, production, consumption, and related socioeconomic activities on nature and the functioning of natural systems, as well as the drivers and pressures causing this impact[82]. The measured footprints are compared against global boundaries within which humanity can continue to live sustainably[83]. Though these measurements and related boundaries are not perfect, they offer indicators that are easy to track and provide an assessment of the environmental impact society has. These footprint boundaries are still based on science, with varying thresholds that are discussed individually. These indicators also assist in monitoring the progress in these footprints.

This report examines five different footprints, utilizing the framework developed by WWF and Metabolic[84]. For the purpose of this report, all global boundaries have been updated to reflect the 2023 population size of approximately eight billion people.

Material and Biomass footprints

The Material footprint, measured by Raw Material Consumption (RMC), serves as an indicator of a country's primary raw material consumption footprint with the end-use in Finland (i.e., the measurement includes imports but excludes exports). It measures the direct environmental burden by quantifying the total volume of materials extracted, transferred, or transformed from nature, in tons. The RMC comprises of four main resource categories: non-metallic minerals (mined minerals, stone, sand and gravel, and other equivalent raw materials), metal ores (iron, nickel, and other metals), biomass (wood, food, and other plant or animal-based products), and fossil energy materials (oil, gas, coal, peat, and other fossil materials).

This footprint measure captures the total volume of resources utilized by a country for its end-use consumption. However, it doesn't assess the specific environmental impacts associated with each type of raw material. For example, it doesn't compare the environmental impact of consuming a ton of sand and gravel versus a ton of oil. The RMC formula can be expressed as follows:

$$RMC = Domestic\ Extraction\ (DE) + Imported\ Raw\ material\ Equivalents\ (IMP_{RME}) - Exported\ Raw\ Material\ Equivalents\ (EXP_{RME})$$

DE encompasses materials extracted domestically for economic use, while IMP_{RME} EXP_{RME} quantify the direct inputs required for importing and exporting volumes of materials. In this way, RMC encapsulates both the immediate use of raw materials and an estimation of production-related waste. However, it intentionally excludes secondary materials like recycled items (e.g., circulated metals) and secondary inputs such as air and water.

The RMC metric, focusing solely on domestic consumption, provides insight into environmental impacts driven by a country's demand, avoiding an overemphasis on industrial production-based economies. This consumption-based approach places responsibility on the end-user by including all the raw materials needed for a product within their nation, doing away with the need to consider where the raw material was extracted or where the product was produced.

In 2023, the global sustainable limit for Material footprint was 6.2 tons per capita, a figure derived from O'Neill et al.'s (2017) review of relevant literature and acceptable boundary limits[85]. This global limit includes both Material and Biomass footprints and is inspired by suggestions from Dittrich et al. (2012) among others. These recommendations advocate that global material extraction should not exceed 50 gigatons (Gt) annually, a threshold that reminisces the consumption levels of 1992, the year of the pivotal Earth Summit in Rio de Janeiro, Brazil[86]. This summit was significant in initiating an ambitious agenda aimed at, among other objectives, crafting national policies to transition from unsustainable consumption patterns. For the purpose of this report, the per capita global sustainability boundary is calculated by dividing the 50 Gt limit by the global population in 2023.

The encompassing global boundary of 6.2 tons per capita spans all four resource categories. For analytical clarity, this report separates the Biomass footprint from the Material footprint, considering it as a distinct measure to facilitate a more nuanced examination of its specific impacts. To isolate Biomass, this analysis employs findings from Krausmann et al. (2008), which indicate that 20% of Biomass is used as raw material[87]. Accordingly, the global sustainability boundary designated for biomass alone is calculated to be 1.2 tons per capita. Consequently, the Material footprint, excluding biomass – comprising non-metallic mineral, metal ores, and fossil energy materials – defines a global limit of 5.0 tons per capita. This boundary enables a targeted assessment of both biomass and non-biomass resource impacts within the broader scope of global material consumption.

Ecological footprint

Ecological footprint (EF) measures the pace at which we consume resources and generate waste, compared to nature's ability to absorb this waste and regenerate these resources. In essence, it accounts for all human demands on the planet, including the food we consume, the space we use for housing and infrastructure, and the forests needed to absorb carbon dioxide emissions from burning fossil fuels. This is calculated by assessing the biologically productive area, or biocapacity (measured in global hectares, usually adjusted per capita), required to produce goods and services as well as absorb waste and emissions consumed. It takes the form of a national balance equation:

$$EF_{Consumption} = EF_{Production} + (EF_{Import} - EF_{Export}),$$

where EF_{Import} and EF_{Export} represent the footprints embodied in imported and exported commodity flows, respectively.

The Ecological footprint of *production* represents the primary demand for biocapacity and is calculated as follows:

$$EF_{Production} = \frac{P}{Y_N} \times Yield\ Factor \times Equivalence\ Factor$$

where P is the amount of a product harvested or carbon dioxide emitted, and Y_N represents the national average yield for P, reflecting either harvest volume or carbon uptake. Yield and equivalence factors vary by land use type and are used to standardize comparisons of land productivity and carbon sequestration across regions. Factors are calculated for six main land categories: built-up areas, farmland, carbon-absorbing areas, forests, pastures, and fishing waters.

Yield factor measures local productivity versus the global average for each type of land use, calculated as the national-to-world average yield ratio, varying by country and year. [88] For instance, since forest land in Finland produces more biomass than the global forest average, it has a higher yield factor than average. Consequently, these forests are potentially able of sequestering more carbon and produce more wood for consumption than average.

Equivalence factor converts specific land use areas into global averaged biologically productive units, based on the ratio of maximum potential productivity for a land type compared to the global average productivity of all biologically productive lands. For instance, a hectare of cropland has an equivalence factor of 2.5, indicating that this hectare is over twice as productive as the average hectare globally, this emphasizing its higher biological productivity.[89]

To align with the sustainability boundaries of our planet, the EF_C must be equal to or fall below Earth's biocapacity. Earth covers approximately 12.2 billion hectares of biologically productive land and water area. When dividing by the global population in 2023, we get a global biocapacity of roughly 1.5 global hectares (gHa) per person.[90]

The concept of Earth's overshoot is highlighted by the discrepancy between the Ecological footprint and Earth's biocapacity. Human demand for natural resources exceeds the planet's regenerative capacity by almost 60%, compared to what Earth can sustain per capita. Essentially, we use up the annual quota of Earth's resources by the start of August, creating an irrecoverable deficit within the same year.[91]

The implications of living in overshoot are significant and include global warming, deforestation, soil erosion, and biodiversity loss potentially leading to ecosystem services collapses. For a comprehensive understanding of when Earth's ecosystems might collapse, it's critical to have a detailed knowledge of the planet's 'balance sheet'.

Phosphorous footprint

Phosphorous footprint quantifies the per capita production-based allocation of synthetic phosphorus fertilizer utilized on cropland, measured in kilograms. This production-based approach accounts for all domestic use of synthetic fertilizers, including both locally produced and imported fertilizers applied to domestic cropland, but excludes any exported and organic fertilizer volumes.

Agriculture contributes significantly to Finland's Phosphorus footprint, primarily through the application of synthetic and organic fertilizers. Notably, 69% of phosphorus found in the sea originates from fertilizer used on cropland[92], a problem worsened by the high demand for animal products, as evidenced by the fact that over half of Finland's agricultural land is committed to producing feed for livestock[93]. If it's not fully absorbed by crops, it can seep into nearby water bodies through surface runoff. This excess phosphorous can cause eutrophication, harming aquatic biodiversity and water quality.

A global sustainability boundary for cropland fertilizer application, excluding manure, is set at 0.8 kg of phosphorus per capita annually[94]. This limit is based on research by Bennett et al. (2011) and further analysis by Steffen et al. (2015). Their findings suggest that capping annual phosphorus use from fertilizers on erodible soils at 6.2 teragrams (Tg) could preserve the health of Earth's freshwater aquatic environments. Maintaining this per capita boundary could also keep freshwater phosphorus levels similar to those pre-industrialization, thus preventing large-scale eutrophication. This boundary complements the global 1.4 kg per capita threshold established to prevent a large-scale ocean anoxic event. However, it does not address the issue of freshwater eutrophication, which is particularly significant for Finland and the Baltic Sea.

It is important to note that these boundaries apply solely to mined phosphorus or synthetic fertilizers; they do not account for manure or wastewater in the global phosphorus cycle. While this global boundary provides a general guideline, specific ecosystems, such as certain freshwater aquifers and the Baltic Sea, may necessitate even lower phosphorus application rates. This is due to limited water exchange, low water volume compared to other oceans, high sensitivity of local ecosystems suited for brackish water, and resultant nutrient buildup.

Nitrogen footprint

Nitrogen footprint, like phosphorous, is quantified in kilograms per capita and is based on the production-based approach of nitrogen fertilizer used on croplands. This production-based approach covers the total domestic use of fertilizers, which includes both locally produced and imported fertilizers used on national croplands, specifically excluding exported fertilizers.

In Finland, the agricultural sector significantly contributes to the country's Nitrogen footprint, with both synthetic and organic fertilizers accounting for approximately 54% of the total seawater runoff[95]. The calculation of Finland's Nitrogen footprint focuses on reactive nitrogen compounds from agricultural sources that contribute to eutrophication. However, it does not include nitrogen oxide (NOx) and nitrogen compounds from non-agricultural sources. Additionally, the footprint measurement does not consider runoff from natural sources.

The global limit for Nitrogen footprint is 7.8 kg per capita of synthetic nitrogen, applied annually as cropland fertilizer.[96] De Vries et al. suggest that maintaining an annual nitrogen usage of 7.8-10.3 kg per capita long term could prevent excessive inorganic nitrogen levels in surface waters, thus preventing eutrophication or acidification in aquatic ecosystems, while still meeting the agricultural demands of a projected global population of nine billion[97].

For this report, the lower limit of this range is used to promote the long-term health of Earth's freshwater environments and to reduce the risk of extensive eutrophication or acidification. Like the Phosphorous boundary, the Nitrogen threshold is considered global. This means that certain water bodies like the Baltic Sea require more restrictive Nitrogen application limits due to their lower water exchange and consequent nutrient build-up. Exceeding the Nitrogen thresholds will eventually lead to harmful algae growth and oxygen-deprived dead zones in water bodies. This highlights the need for strict Nitrogen control to protect aquatic ecosystems and maintain water quality.

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