SustainaWeekly

Financing green hydrogen

- **Economist: Green hydrogen could play an important role in the transition towards a low carbon economy. However, the uncertainty of renewable power supply, the technological immaturity, the lack of clarity about demand, and the absence of associated infrastructure weigh on the business case for green hydrogen. PPA usage, the alternative purposes of green hydrogen, and government intervention are among the remedies.**

- **Strategist: The ECB stress-tested the economy under different transition scenarios over an 8-year horizon. Corporates are affected by transition risks through lower profitability and higher leverage, which result in higher credit risk. This increased risk ultimately feeds into banks' own credit risk, which could lead to significant expected losses. Transition risk for the banking sector in the euro-area is very much concentrated within a few large banks.**

- **Sector: Reducing emissions and reaching net zero for heating is a complex task. One option is to burn fuels or mass but these need to be sustainably resourced. Heat can be absorbed from other sources such as the sun, ground, air, water or rest heat. Renewable electricity can also be converted into heat. So there are several options but these options are currently more expensive than just burning fossil fuels.**

- **ESG in figures: In a regular section of our weekly, we present a chart book on some of the key indicators for ESG financing and the energy transition.**

The financial sector has a crucial role to play in boosting the energy transition by allocating and steering the funds towards clean and climate- friendly technologies, one of which is green hydrogen. However, private investments to boost the rollout of green hydrogen still fall short. In this SustainaWeekly, we first focus on the obstacles limiting the potential to finance green hydrogen and propose potential remedies to reduce these risks. We then go on to assess the key results of the ECB's stress test for corporates and banks. Finally, we zoom in on alternative heating technologies to reduce greenhouse gas emissions.

Enjoy the read and, as always, let us know if you have any feedback!

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Financing green hydrogen

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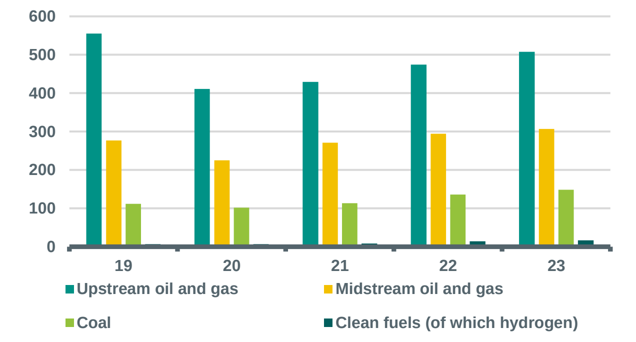
- **Green hydrogen could play an important role in the transition towards a low carbon economy…**
- **…But the uncertainty of renewable power supply, the technological immaturity, the lack of clarity about demand, and the absence of associated infrastructure are the main risks weighing on the business case for green hydrogen**
- **PPA usage, the alternative purposes of green hydrogen, and government intervention are among the remedies to ameliorate the business case for investors**
- **The current risk-return profile for green hydrogen is best suited for institutional investors such as development banks, along with oil and gas companies**

Introduction

Within the financial sector, the last few years have witnessed a shift from a profit-driven paradigm towards incorporating social and environmental aspects in the investment decision making. When it comes to climate change, most investors acknowledge physical and transition risks and incorporate them into investment decisions. At the same time, the financial sector has a crucial role to play in boosting energy transition by allocating and steering the funds towards clean and climate-friendly technologies, one of which is green hydrogen. With its multiple advantages, green hydrogen is set to have a prominent position among the set of possible fuels of the future (see our note on green hydrogen **here**). In this direction, Europe has put in place a strategy for green hydrogen with a goal of reaching 10 million tons of domestic production by 2030, while importing an equivalent amount. Such a goal entails huge funding requirements both public and private. However, private investments to boost the rollout of green hydrogen still fall short even though the needed funds are readily available (read more **here**). Motivated by this observation, this note aims to answer the following question: what are the obstacles limiting the potential to finance green hydrogen? We answer this question from an investor perspective by exploring the risks along the value chain of green hydrogen and propose potential remedies to reduce these risks and ameliorate the business case for green hydrogen.

Global fuel supply investments (2019-2023)

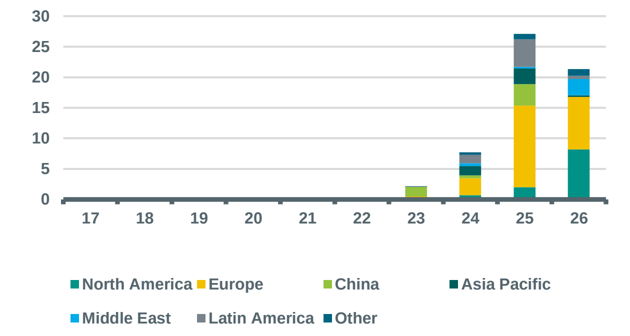
Units: billion USD (2022)



Source: IEA, ABN AMRO Group Economics

Hydrogen announced capacity additions (2017-2026)

Unit: GW



Source: IEA , ABN AMRO Group Economics

Risks along the value chain

There are multiple bottlenecks along the value chain for green hydrogen, which constitute different sources of uncertainties that weakens its business case and deter investments. The value chain for green hydrogen can be split into four broad categories: renewable power production, the electrolysis process, the associated infrastructure, and the final utilization of produced hydrogen.

Renewable power production

In order for hydrogen to gain the green label, it should be produced using renewable power. Thus, from the supply side, green hydrogen production is tied to the availability of renewable power supply. However, the uncertainty surrounding the time schedules for renewable capacity deployments is increasing the risks of insufficient power supply to run the electrolysis process, thus weakening the business case of green hydrogen. The delays in investments are tied mostly to long permitting times, rising capital costs (increase in interest rates and production inputs), and the lack of supporting infrastructure. Moreover, as the capacity is taking more time to be built, coupled with a rising demand, renewable power will be expensive, which translates into a higher cost of green hydrogen production, along with lower competitiveness against its fossil counterparts, which in consequence worsens its business case even further.

The electrolysis process

From the technology side, green hydrogen is mainly produced through a water electrolysis process that separates the water molecules into hydrogen and oxygen. There are currently three types of electrolysers, and each has its (dis)advantages. Alkaline electrolysers are relatively cheap, but their performance is sensitive to any interruptions. Proton Exchange Membrane (PEM) electrolysers, on the other hand, are more flexible and can handle interruptions better, but this comes with higher cost tag. The third type is Solid Oxide electrolysers, which are a less mature type of technology and still need more time to be commercialized. Green hydrogen that relies on Alkaline or PEM electrolysers is on a demonstration-early adoption phase, while green hydrogen produced using Solid Oxides electrolyser is at large prototype/demonstration phase. Accordingly, the scalability of these technologies is still to be proven. Additionally, the electrolysis process relies on different components, produced by different parties, that may not be compatible or work well together, which result in the absence of performance guarantees by manufacturers. This in turn increases the technological risk of investing in electrolysers and weakens its business case.

The final use of produced hydrogen

Green hydrogen is envisioned to be *the* transition solution for hard to abate sectors where electrification is not possible. However, these sectors need to invest in adjusting their processes in order to incorporate green hydrogen into their production mix. But for these investments to take place, clarity on the timeline for green hydrogen availability is needed. At the same time, absence or uncertainty of green hydrogen demand, as the transition in industry is stalled, weakens the business case for green hydrogen. Accordingly, there is a “chicken-egg” dilemma: transition in industry depends on the availability (the supply) of green hydrogen, while green hydrogen investments require demand certainty.

Associated infrastructure

Green hydrogen projects require a supporting infrastructure to roll out. From the upstream of the value chain, there is a need for high voltage grid extensions that facilitate the delivery of renewable power to the hydrogen premises, which are not (yet) always readily available. For example, there are currently many challenges with regards to bringing back energy generated from offshore wind farms to the shore Additionally, after green hydrogen has been produced, there is also a need for transportation and infrastructure to the final user. The type of final user will also ultimately determine the most appropriate form for this hydrogen to be carried. For example, delivering hydrogen as a fuel for ships is done best by transforming it to ammonia especially for long distance international trips, while using it in industrial process can be in a gaseous or liquid form. Each form requires a different type of infrastructure and associated investments, which translate into different regulation, permitting procedures, and technical burdens. Needless to mention, the scale of funding needed for these infrastructural investments is huge. These complex interrelated aspects compromise additional uncertainty that undermines the feasibility of green hydrogen projects.

Is regulation helping the business case of green hydrogen?

Sometimes certain regulation induces some restrictions and market dynamics that restrict the full potential of a technology and weakens its business case from an investor perspective. For example, the European Union has set relatively stringent rules for the production of green hydrogen. One of which is that the electrolysers should be powered by a newly built dedicated solar and wind power installations, with an initially lenient monthly compliance, that needs to turn into an hourly compliance basis as of 2030. These rules favour the flexibility of electrolysers and by consequence the PEM electrolysers, which are relatively more expensive. At the same time, the intermittency of renewables entails that the production of green hydrogen is vulnerable to weather conditions, which entails that electrolysers may not operate at their full capacity when the wind is not blowing or clouds are covering the sky. This, in turn, increases the cost for green hydrogen production for the EU and makes it less competitive[1]. Another example is the adoption of different calculation mechanisms for emissions and carbon credits across countries, which means that the value associated to green hydrogen usage by final sectors downstream the value chain could differ between trading partners, resulting in large discrepancies between companies and countries. As a consequence, the business case for downstream utilisation projects could be compromised and may slow down the offtake of green hydrogen. A third example relates to the conditions associated to subsidies. In the US, the accessibility of subsidies for offshore wind projects is tied to the usage of domestic components. This conditionality, along with rising capital cost, made many offshore projects unprofitable as domestic components are witnessing a supply shortage for needed materials such as steel. By consequence, delays for hydrogen projects can be expected and its business case is adversely affected.

Remedies to boost investments

Due to the aforementioned uncertainties, the risk-return profile for green hydrogen projects is still not attractive for most investors. In this section, we outline potential remedies that can relax some of these risks for investors and boost investments.

With regard to renewable power supply, the usage of Power Purchase Agreements (PPA) can help to improve the business case for renewable power investors and reduce the supply uncertainty for electrolysers investors. At the same time, supplying different components of the electrolysers from the same supplier will be helpful in increasing the compatibility of different components in the electrolysis process and encourage manufacturers to extend performance guarantees that reduce the technological risk for investors.

With regards to demand uncertainty, the diversification of green hydrogen usage could be considered as a remedy here. That is, even in the case of the absence of demand from the final sector, green hydrogen can be used as a medium of storage to stabilize the grid. It can also reduce grid congestion and the need for grid extensions by using alternative off-grid hydrogen networks to transport embodied electricity to where it is needed. Furthermore, produced hydrogen could be exported.

The remaining remedies require government intervention in terms of providing a clearer and compatible vision for green hydrogen, a timeline for infrastructural developments, shorter permitting times along the value chain, and using the proceeds of carbon prices to finance the required infrastructure or speed up the adoption phase where private capital is scarce. Moreover, on different levels, the government can facilitate the coordination between related stakeholders to resolve bottlenecks and boost green hydrogen investments. For example, prioritizing the use of green hydrogen to sectors that are most in need is also key to boost the transition in these sectors in time and with minimal delays. Furthermore, the usage of regulation mandating the use of hydrogen in final sectors, such as transport or manufacturing, would boost demand and reduce uncertainty for investors. Finally, the higher cost of green hydrogen compared to alternative fossil fuel and grey hydrogen require Capex and Opex subsidies that reduce the cost at first stance. Other tools that increase the competitiveness of green hydrogen, such as the usage of grants and the usage of contracts for difference, could also come into play.

The finance sphere

Green hydrogen projects are long-term capital intensive with relatively high risk, which make institutional investors the most appropriate source of finance for these projects. The long term and climate friendly nature of green hydrogen projects fits the mandate of pension funds and insurance companies, but the current risk profile of these projects is higher than these institutions can bear as they are quite risk averse. But, as we get more certainty along the value chain, more finance could be unlocked from these institutional investors. For current risk level however, project finance will be the main financing instrument for green hydrogen. The development theme of green hydrogen is also important along with its international aspect, which make it relevant to development banks, especially in countries abundant in renewable power potential. Furthermore, oil and gas companies aiming at diversifying their portfolio and repurposing the existing fossil fuel infrastructure, along with the associated reputational benefits, make green hydrogen an attractive opportunity for these

[1] Different rules have been adopted by China that favours the Alkaline cheaper variant.

companies. These companies can invest at the same time in multiple segments along the value chain (renewable power and electrolysis, for example), which reduces many of the aforementioned risks. Finally, diversifying the available funding sources for hydrogen projects could play an important role for large-scale deployment of green hydrogen.

We aim to dive more in the incentives of different stakeholders in the finance sphere in a future note.

ECB shows that transition risks will have a significant impact on corporates and banks by 2030

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- **The ECB published a paper which stress-tests the economy under different transition scenarios over an 8-year horizon**
- **It combines non-climate developments from macroeconomic projections with climate-related shocks identified by the NGFS, while focusing on the short-term impacts (ie before 2030).**
- **We focus on the impact on corporates and banks in this paper**
- **The ECB shows that corporates are affected by transition risks through lower profitability and higher leverage, which result in higher credit risk. This increased risk ultimately feeds into banks' own credit risk, which could lead to significant expected losses**
- **The ECB paper also shows that transition risk for the banking sector in the euro-area is very much concentrated within a few large banks**

The ECB published a paper earlier this month where it shows the impact of different transition scenarios in the EU economy from 2022 until 2030 (see here). The scenarios were defined as following: an "accelerated transition" scenario, which assumes that a green transition starts immediately, allowing a reduction in emissions by 2030 in line with the goals of the Paris Agreement; a "late-push transition" scenario, which assumes that adverse macroeconomic developments lead to a green transition starting only in 2025 (but is still intense enough to achieve Paris-aligned emission reductions by 2030); and a "delayed transition" scenario, which also starts only in 2026, but would be " smoother" (being therefore less costly in the short-term), meaning it would not be sufficiently ambitious to reach the Agreement goals by 2030. The scenarios were based on the NGFS scenarios framework, with a few key adjustments:

- the "accelerated transition" scenario assumes that the NGFS "delayed transition" scenario starts already as of 2023, instead of 2030;
- the "late-push transition" scenario assumes that until 2025, the economy follows the NGFS "current policies" scenario, but aligns with the NGFS "delayed transition" scenario from 2025 onwards
- the "delayed transition" scenario assumes that until 2025, the economy follows the NGFS "current policies" scenario, and that the NGFS "net zero 2050" scenario would start in 2026

A summary of the scenarios used by the ECB can be found on the table below.

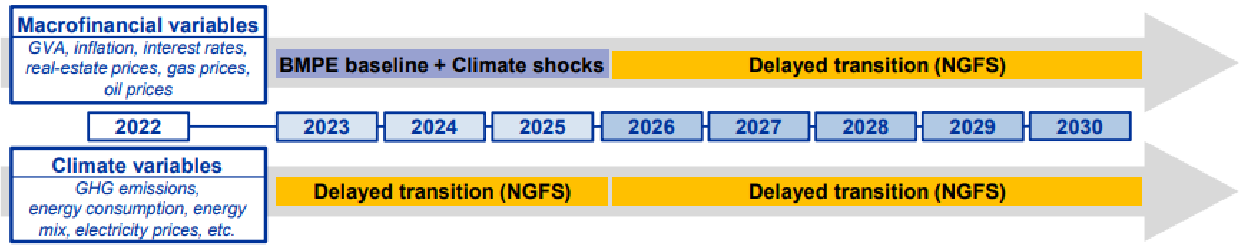
Summary of key assumptions under each ECB scenario

	S1 Accelerated transition	S2 Late-push transition	S3 Delayed transition
Scenario implementation	The NGFS delayed transition scenario was front-loaded and diluted through linear interpolation to model short-term climate shocks to macro-financial variables and produce medium-term projections.	The NGFS current policies scenario was used to model the absence of climate action in the short term. A front-loaded NGFS delayed transition would start only in the medium term.	The NGFS current policies scenario was used to model the absence of climate action in the short term. An orderly transition that would follow the NGFS net zero 2050 scenario would start only in 2026.
Emissions	Compatible with a +1.5°C temperature target by the end of the century.	Compatible with a +1.5°C temperature target by the end of the century.	Compatible with a +2.6°C temperature target by the end of the century.
Investments	High and spread over eight years, with more funding at the beginning.	Very high and concentrated in the medium term.	Medium, as required to implement an orderly transition.
Energy prices	Very high and increasing further in the first few years, providing an incentive for firms to transition rapidly.	Fossil fuel prices stay constant at a high level before the transition starts and increase thereafter; electricity prices are strongly penalised by late action in the medium term.	Constant at a high level before the transition starts and gradually increasing thereafter.

Source: ECB.

The innovative aspect of the ECB's paper is that it (i) combines non-climate developments from macroeconomic projections with climate-related shocks identified by the NGFS, and (ii) focuses on the short-term impacts of transition risk (ie by 2030). The overview below also illustrates how the ECB has combined macroeconomic developments with climate variables (in this specific case, for the construction of the "accelerated transition" scenario).

Illustration of how macroeconomic and climate variables come together in the accelerated transition scenario



Source: ECB.

Below, we highlight the key take-aways focusing first on corporates, and then on banks.

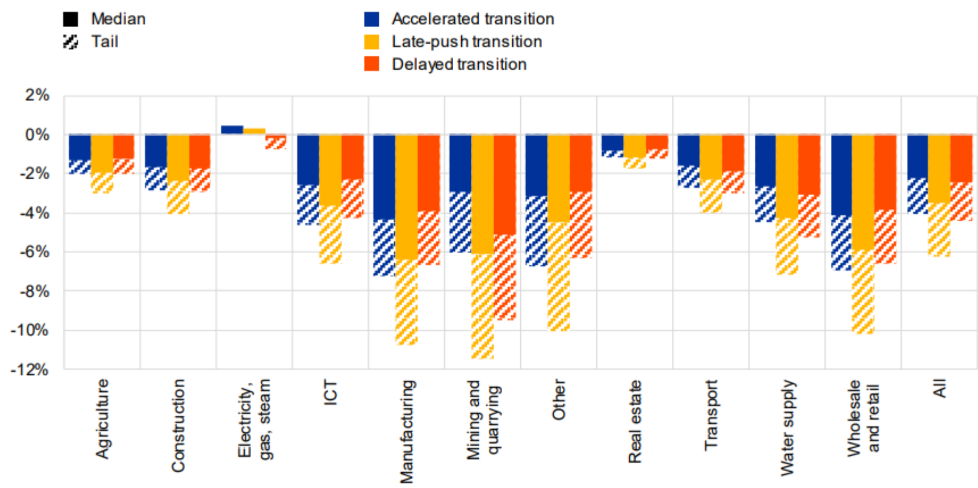
1. Corporates

The transition to a low-carbon economy affects firms' profitability and leverage

The transition to a low-carbon economy will affect corporates in the EU through: (i) lower profitability, coming from a supply-side, and partially carbon tax-induced, energy price shock (higher oil and gas prices), which would add to firms' production costs and operating expenses; and (ii) higher leverage, as firms need to invest in carbon mitigation activities to replace their current stock of brown assets and reduce their carbon footprint. These investments are assumed to be mostly funded via bank loans. The charts below highlight the ECB's findings in terms of the impact for both, profitability and leverage, across different sectors, across the different scenarios.

Change in sector-level profitability due to the transition across different NGFS scenarios

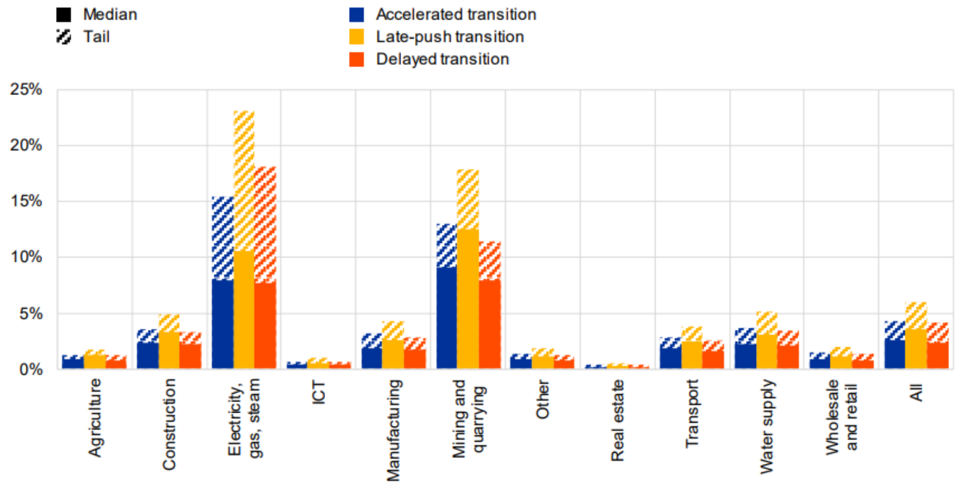
Absolute difference in percentage points between 2022 and 2030



Source: ECB. Note: tails are defined as the 25th percentile. Profitability is defined as revenues minus operating and financial expenses, over total assets.

Change in sector-level leverage due to the transition across different NGFS scenarios

Absolute different in percentage points between 2022 and 2030



Source: ECB. Note: tails are defined as the 75th percentile. Leverage is defined as total debt over total assets.

A late-push transition would lead to energy prices similar to those experienced during the Russian invasion of Ukraine, which will result in a severe deterioration in profitability, in particular for energy-intensive firms. The profitability impact in the delayed transition scenario is not as severe given that the impact is likely to be felt by firms after 2030. Overall, the ECB analysis indicates that profitability would decrease by 2 to 3 percentage points for the median euro area firm, and by twice as much for the median firm in energy-intensive sectors (e.g. mining, manufacturing and retail) and for firms in the tail of the distribution. Furthermore, as we previously mentioned, higher investments into the energy transition will also increase firms' indebtedness, which will be higher for firms that require a larger scale of transition (mostly mining and electricity). In general, the ECB concludes that the leverage ratio would increase by around 3 to 4 percentage points for the median firm across sectors in the euro area, while it would increase by 3 to 4 times as much for the median firm in the mining and electricity sectors.

The ECB findings are also in line with previous research that ABN AMRO has conducted. For example, by using scope 1 and 2 emission data, we were able to see which sectors are mostly vulnerable to an increase in energy prices from an EBITDA margin perspective (see **here**).

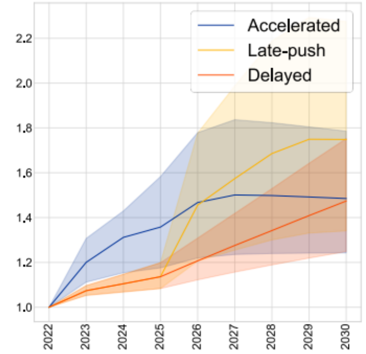
Additionally, cumulative investments until 2030 would reach higher levels under the late-push scenario compared to the accelerated transition due to the later start of the transition, which would induce a slower learning curve for renewable energy production and therefore more expensive investments. This is particularly costly for electricity firms. Nevertheless, both scenarios result in the same amount of installed capacity of renewable energy by 2030. On the other hand, while the cumulative investment under the delayed transition scenario is expected to be lower (around EUR 2.5tri vs. around EUR 3tri for the other scenarios), that is because installed renewable energy capacity is also estimated to not reach the same levels as under the other two scenarios. In fact, the ECB estimates that renewable energy capacity under the delayed transition scenario will be 2,000 GWh less than in the other scenarios.

Higher leverage and lower profitability feed into higher credit risk

The increase in leverage and the decline in profitability can be then translated into higher probabilities of default (PDs), which are used as a proxy to capture credit risk for these corporates. As shown in the charts below, corporate PDs would increase the most under the late-push transition scenario. The chart below shows that, although credit risk by 2030 is lower for the delayed transition scenario, it is expected to increase further and reach its peak after 2030. On the other hand, under the accelerated and late-push transition scenarios, credit risk would already start to decrease in the second half of the period. Overall, the delayed transition scenario implies not only that *transition risk* would continue to negatively affect corporations for a longer period, but also that *physical risk* would have a stronger effect on the economy (recall: under this scenario, temperatures are not expected to achieve the reductions required as per the Paris Agreement). Furthermore, the chart below (right hand side) also show that the distribution of corporate PDs would also be wider under the late-push scenario, indicating more extreme behaviours in the tails.

Credit risk increases due to the transition

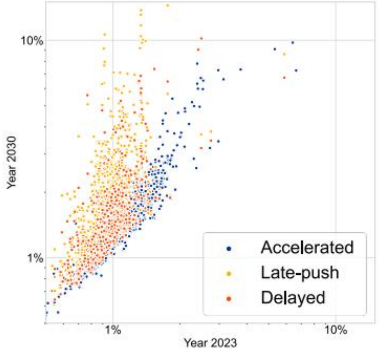
Change in PDs, Index 2022=1



Source: ECB. Note: line indicates median corporate PD. Shaded area indicates the distribution of corporate PDs.

PDs are higher and more widespread across all sectors under the late-push and delayed scenarios

Median sector-level PDs (logarithmic scale)



Source: ECB. Note: PD shown in logarithmic scale. Each dot correspondents to a NACE 4 sector.

2. Banks

Euro-area banks are very vulnerable to transition risks

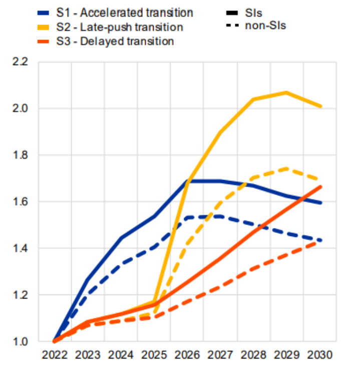
The ECB computed the PD of a bank's loan portfolio by using the PD of corporates (as previously shown), weighted by the bank's exposure to that corporate (for that, it used AnaCredit – the euro area credit register). The data was then aggregated at bank level.

The results indicate that:

- 40% of the total loan volume of the euro area banking system is towards energy-intensive sectors (this is greater for significant institutions (SI) - around 42%)
- Less than 10% of all banks account for 90% of all exposure to energy-intensive sectors, indicating that transition risk will be heterogenous across banks
- The top 10% of the banks with highest exposure to energy-intensive sectors account for one-third of the total lending in the euro area
- Overall, the ECB paper shows therefore that the euro banking system is very exposed to transition risk (and that transition risk increases the bank's credit risk), but that this risk is mostly concentrated within a few (large) banks (known as significant institutions, or SIs, as shown in the chart below, on the left hand side)

SIs are more exposed to the transition

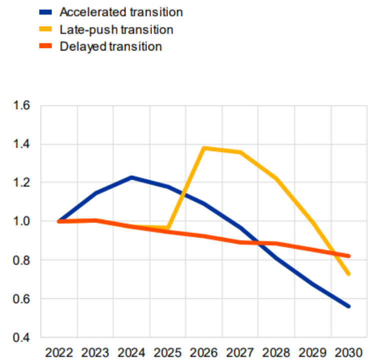
Change in corporate loan portfolio PDs, Index 2022=1



Source: ECB. Note: SI = Significant institution.

TCI is significantly lower in the accelerated scenario

Change in transition-to-credit risk indicator (TCI), Index 2022=1



Source: ECB. Note: PD shown in logarithmic scale. Each dot correspondents to a NACE 4 sector.

Furthermore, the ECB paper shows that under a scenario where the Paris Agreement goals are reached by 2030 (accelerated transition and late-push scenarios), the peak in bank's credit risk increase will be reached before 2030, and will slowly start to return to "normal" levels thereafter (see chart above on the left hand side). However, under a delayed transition scenario, transition risk, and thus credit risk, is expected to continue to increase after 2030 (and this is also when physical risk is also expected to start to feed within PDs).

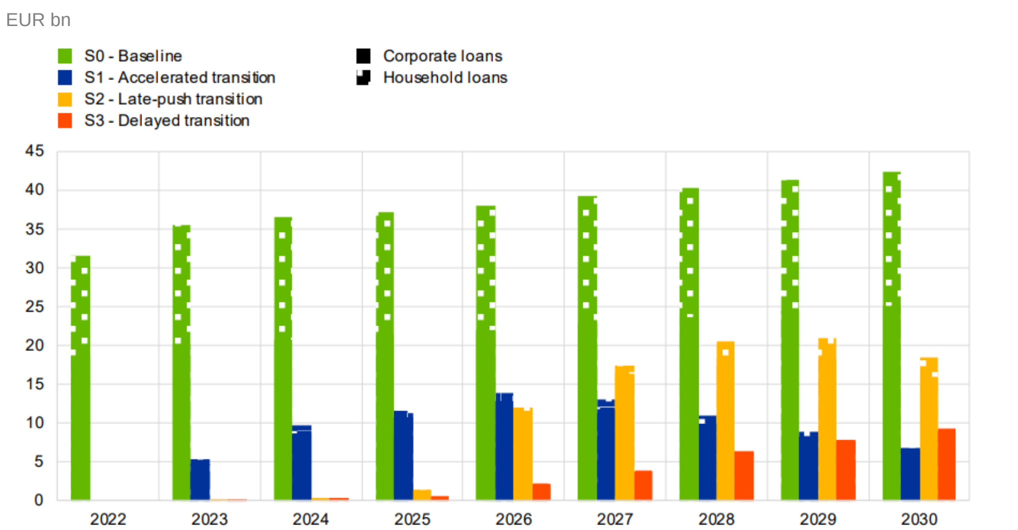
Credit risk might be similar across different scenarios, but exposure to climate risks are very different

The paper also makes use of a metric called "transition-to-credit risk intensity" (TCI), which is calculated as the product of the borrower's GHG emissions and (projected) PDs, weighted by borrowers' loan exposure. This metric captures therefore not only the bank's credit risk (corporate PD weighted by the bank's exposure), but also transition risk (proxied by emissions), serving as a metric to assess both, banks' "point-in-time" exposure to credit risk, as well as their forward-looking exposure to transition risk in terms of outstanding CO2 emissions. By looking at TCIs, we see that despite credit risk from banks reaching similar levels by 2030 under the accelerated and delayed transition scenarios (see chart above on the left hand side), the transition-to-credit risk intensity is actually significantly lower under the accelerated scenario (see chart above on the right hand side). This indicates that, while a late-push scenario would affect banks' credit risk more severely by 2030 (in comparison to delayed transition), the long-term transition and physical risk implications would be more acute under a delayed transition scenario. All in all, the analysis shows that while different transition paths can result in similar credit risk levels in the economy by 2030, exposures to climate risks are very different.

Furthermore, the ECB paper estimates that annual losses for banks from transition risks in the short-term (which include then corporate loan portfolios, as well as exposures to households) could amount to as much as EUR 21bn under a late-push scenario, which contrasts to EUR 13bn for the accelerated transition scenario. Under the delayed transition scenario, expected losses could reach EUR 9bn up to 2030, which is lower than the other two scenarios due to milder transition efforts. However, this is expected to increase further after 2030 due to greater long-term transition and physical risks, while under the late-push and accelerated transition scenarios, banks' losses are expected to peak before 2030. The expected losses are estimated as "additional" to the already-estimated losses using macroeconomic developments as per forecasts from BMPE projections, and climate variables as per the NGFS "current policies" scenario, where no additional transition risk being accounted for (green bars in the chart below).

The total expected annual losses (that is, excess transition risk losses as well as losses stemming from macroeconomic developments and current climate policies – the "baseline scenario") could amount to as much as EUR 65bn under the late-push scenario.

Banks are expected to face big losses stemming from transition risks



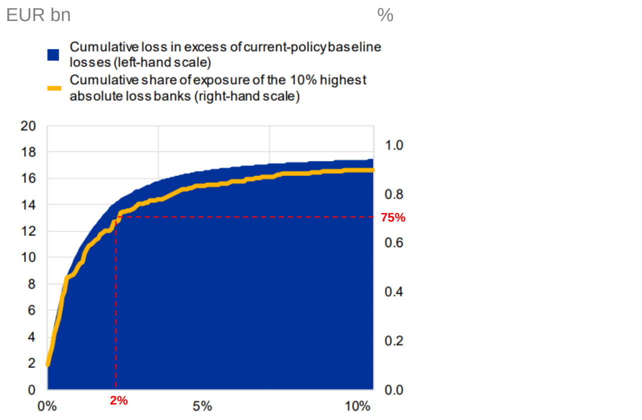
Source: ECB. Note: Baseline scenario indicates losses from (non-climate) macroeconomic developments and additional climate scenarios (ie under current climate policies). Total sum of expected losses under each scenario is the sum of the green bars (baseline) and the corresponding blue/yellow/orange bars. Shaded areas indicates expected losses stemming from household exposures.

Exposure to transition risks is concentrated within a few banks

As previously noted, the ECB does not expect banks' losses in the euro area to be homogenous. Under the late-push scenario, the central bank expects 10% of the banks to see annual expected losses almost double by 2030 compared to 2022 levels, with half of this increase stemming from transition risks. Zooming into the 10% banks that have the highest absolute expected losses (i.e. "tails" of the distribution), the ECB concludes that 2% of these banks account for 75% of all total expected losses by 2030, while also accounting for 65% of total loan exposures in the euro area (see chart below on the left hand side).

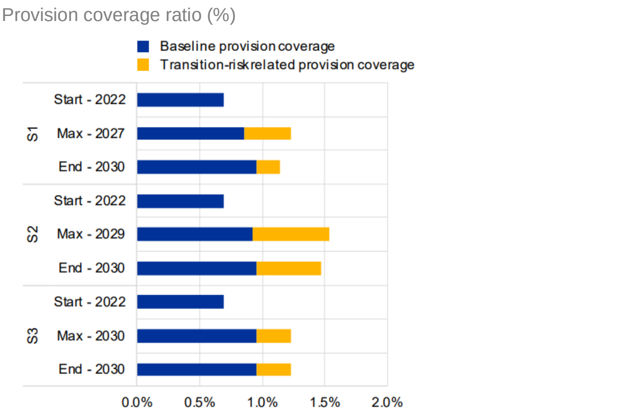
Expected losses are covered via provisions – hence, the provision coverage ratio (provisions overt total loan volume) for banks' are estimated to increase from 0.69% in 2022 (stage 1 loans) to almost 1.5% until 2030 in the late-push scenario (see chart below).

Expected losses concentrated in a few large banks



Source: ECB

Higher expected losses also increase provisions



Source: ECB. Note: S1 = Accelerated transition, S2=Late-push transition, and S3=Delayed transition. Coverage ratio calculated as aggregated provisions and expected losses divided by total outstanding loan volume based on IFRS stage 1 loans.

On aggregate, the annual losses for the median bank stemming from transition risks over the next eight-years would range between 0.6% and 1% of the portfolio, but would be double that for the 10% of most vulnerable banks, pointing to a limited impact relative to portfolio size and capital generation capacity of the banks concerned.

Heating technologies to reduce emissions

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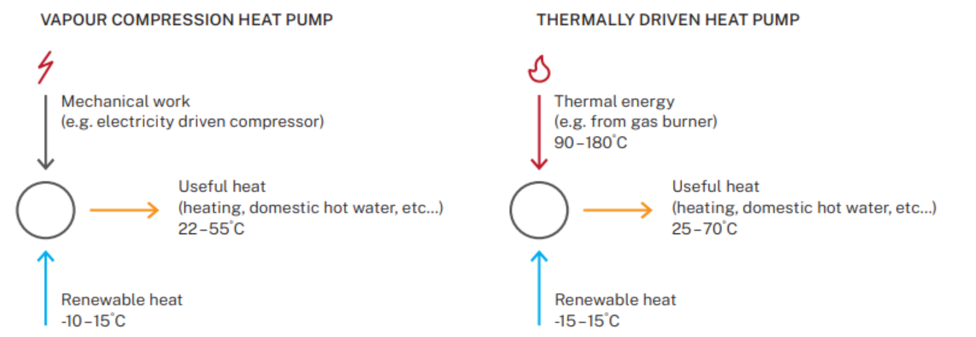
- **Reducing emissions and reaching net zero for heating is a complex task**
- **One option is to burn fuels or mass but these need to be sustainably resourced**
- **Heat can be absorbed from other sources such as the sun, ground, air, water or rest heat**
- **Renewable electricity can also be converted into heat**
- **So there are several options but these options are currently more expensive than burning fossil fuels**

Introduction:
Life on earth depends on heat for survival. In the classic way, heat is generated by burning something (a fuel or a mass) to heat the air or a liquid that can move in a controlled way. For example, burning wood or gas has been the traditional way of heating. More than 70% of heating and cooling is generated from fossil fuels. To move away from this traditional way of heating and reduce greenhouse gas emissions the process becomes far more complicated. In this note we zoom in on alternative heating technologies to reduce greenhouse gas emissions. We first explain what heat is and then focus on the sources of heat and the technologies.

What is heat?
Heat is the thermal energy that is transferred from one body to another as the result of a difference in temperature. So if two bodies at different temperatures are brought together, energy is transferred, i.e. heat flows from the hotter to the colder body. It is transferred through conduction, convection and radiation. All substances above absolute zero have thermal energy, which means that the particles contained in them have some form of motion. In contrast, when sitting outside on a cold day you will feel "cold" because the heat transferred from the sun to you is less than the radiant heat you are giving off (along with convective heat transfer cooling you off). The most significant radiant heat sources in your home include heat from the walls, roof, windows, and your body. Convection is the energy transferred by molecular motion. Radiation is the energy transferred by electromagnetic waves and conduction is the energy transferred by direct contact.

Sources of heat in a zero-emission world
Continue to burn something
To reduce emissions to create heat, fossil fuels could be replaced by fuels that emit less or no emissions. Examples are burning wood from sustainably resourced wood. Burning this wood is carbon-neutral as the CO_2 emissions emitted during burning are equal to trapped emissions during the growth of the trees. Another example is the use of bio-gas, bio-methane or bio-LPG but the availability and/or production of these fuels are too limited to replace the use of fossil fuels so this is a major challenge. Burning fuel would be the easiest solution to create heating. Boilers and thermal heat pumps burn fuel to create heat. A boiler heats a fuel to transfer the heat to water. The hot water is then pumped around the home. In power plants, boilers are used in order to produce high pressured steam by heating water so the plant can generate electricity.

How does a thermally driven heat pump work



Source: European Heating Industry, European Heat Pump Association

Thermally driven heat pumps are heat pumps using heat or an engine to drive the sorption or compression cycle. There are three types of thermally driven heat pumps: gas sorption heat pump, thermal compression heat pump and gas engine heat pump. The graph above shows how it works.

To absorb the heat from a source

The sun as heat source

It is also possible to absorb heat from a source. It can be absorbed from the sun, from the air or water around us or from the heat deep in the ground. We start with technologies that are able to absorb heat from the sun.

Solar thermal technology converts sunlight into heat, which is then used to produce hot water, heat or even cool buildings. Most solar thermal systems work in combination with a heater. For example, a condensing boiler or a heat pump, which operates when heat demand is too high for the solar system alone. On average, a single family house can satisfy up to 60% of its heat demand for domestic hot water with solar energy. A solar heating system is composed of: solar collectors, roof-mounted elements that collect energy from the sun, a hot water tank to store the water heated by the system, a circuit, and a heat exchanger to transfer heat from the collectors to the hot water storage tank. Installation costs of a solar thermal heating system are generally quite expensive as you have to factor in scaffolding, plumbing, and the required moderations to your roof. An example is solar thermal roof panel. There are two closed circuits with a heat exchanger. In the primary circuit, the cold heat transfer fluid passes through the solar panels. Radiation from the sun heats it and goes to a heat exchanger to transfer thermal energy to the secondary circuit and repeat the cycle. In the secondary circuit, the heat transfer fluid goes to the storage system. Inside the storage system, it gives up its thermal energy to the water stored inside. There are several solar thermal technologies: unglazed solar collectors, transpired solar air collectors, flat-plate solar collectors, evacuated tube solar collectors, thermodynamic solar panels and concentrated solar power.

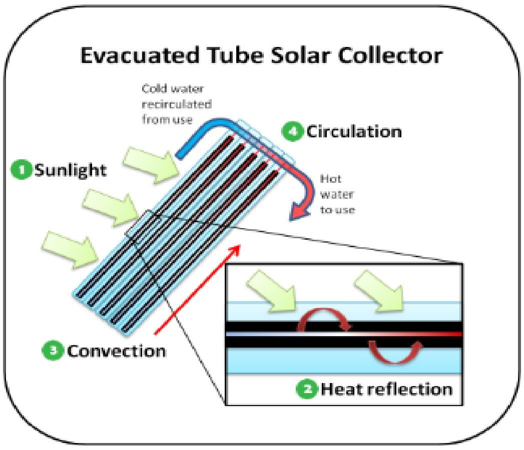
In unglazed solar collectors a heat conducting material absorbs sunlight and transfers the energy to a fluid passing through or behind the heat-conducting surface. It doesn't have a glass covering for the absorber. The collectors work best for low-temperature applications (small or moderate) that require a temperature below 30 degrees celsius such as swimming pool heating and space heating.

Transpired solar air collectors typically consist of a dark-coloured, perforated metal cladding material mounted on an existing wall on the south side of a building. A fan pulls outside air through the perforations and into the space behind the metal cladding, where the air heats to as much as 30°F-100°F (up to 38 degrees Celsius) above the ambient air temperature. The fan then pulls the air into the building, where it is distributed through the building's ventilation system. The transpired solar collector is a proven but still an emerging solar heating technology. This type of technology is best for heating air and ventilating indoor spaces (**www.epa.gov**).

In glazed flat plate collectors consist of copper tubing and other heat-absorbing materials inside an insulated frame or housing, covered with clear glazing (glass). Glazed flat-plate collectors can operate efficiently at a wider temperature range than unglazed collectors. They can be used for applications of up to about 80 degrees celsius. Flat-plate collectors are often used to complement traditional water boilers, pre-heating water to reduce fuel demand. The design of solar panel is, overall, slightly less compact and less efficient when compared with an evacuated tube system, however this is reflected in a cheaper price. This design of solar can work well in all climates and can have a life expectancy of over 25 years.

Evacuated tube collectors feature thin, copper tubes filled with a fluid, such as water, housed inside larger vacuum-sealed clear glass or plastic tubes. Evacuated tubes use the sun's energy more efficiently and can produce higher temperatures than flat-plate collectors for a few reasons (up to 120 degrees Celsius). First, the cylindrical shape of evacuated tubes means that they are able to collect sunlight throughout the day (from many different angles) and at all times in the year. Second, the tubes also have a partial vacuum within the clear glass enclosure, which significantly reduces heat loss to the outside environment - it reduces conduction and convection energy transfer losses. It is one of the most popular solar thermal systems in operation. The tubes can be replaced individually if one becomes faulty, avoiding the need to replace the whole collector. The system is an efficient and durable system with the vacuum inside the collector tubes having been proven to last for over twenty years.

How evacuated tube solar works

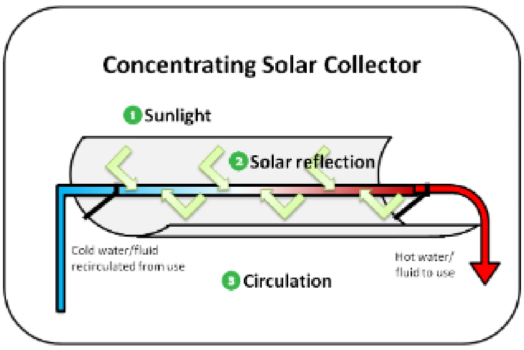


1. **Sunlight:** Sunlight hits a dark cylinder, efficiently heating it from any angle.
2. **Heat reflection:** A clear glass or plastic casing traps heat that would otherwise radiate out. This is similar to the way a greenhouse traps heat inside.
3. **Convection:** A copper tube running through each cylinder absorbs the cylinder's stored heat, causing fluid inside the tube to heat up and rise to the top of the cylinder.
4. **Circulation:** Cold water circulates through the tops of the cylinders, absorbing heat.

Source: www.epa.gov

Thermodynamic solar panels are a new development (and need more research and development). They are solar-assisted heat pumps. They are a hybrid between a solar thermal panel and a heat pump. They can create power from not only direct sunlight but also from heat in the air. They may resemble solar panels, but their function is more like a heat pump. They are deployed on the roof or walls and they don't have to be south facing. These panels work by circulating an extremely cold liquid refrigerant throughout the veins within the panel. As the refrigerant enters the system, it typically has a temperature of around -22°C. The panels absorb heat from the surrounding air, transferring the energy to the cold refrigerant. In this process, the refrigerant's temperature increases, ultimately turning it into a gas. The gas is then compressed which raises its temperature and it will then be passed on to a heat exchanging coil that is located within a hot water cylinder. The hot gas then passes through a heat exchanger, transferring its thermal energy to the water supply, heating it for domestic use. Finally, the refrigerant returns to its original liquid state and re-circulates through the system, starting the process again. The advantage of thermodynamic panels is that they can operate in various weather conditions, even at night or during cloudy days. They absorb heat from direct sunlight, but can also pull heat from ambient air. This is due to their ability to extract heat from the air, similar to how ground source heat pumps work. They can be used for domestic hot water production and underfloor space heating.

How concentrated solar collector works



1. **Sunlight:** Sunlight hits a reflective material (i.e., a mirrored surface), usually in the shape of a trough (shown here) or a dish.
2. **Solar reflection:** The reflective material redirects the sunlight onto to a single point (for a dish) or a pipe (for a trough).
3. **Circulation:** Cold water or a special heat transfer fluid circulates through the pipe, absorbing heat.

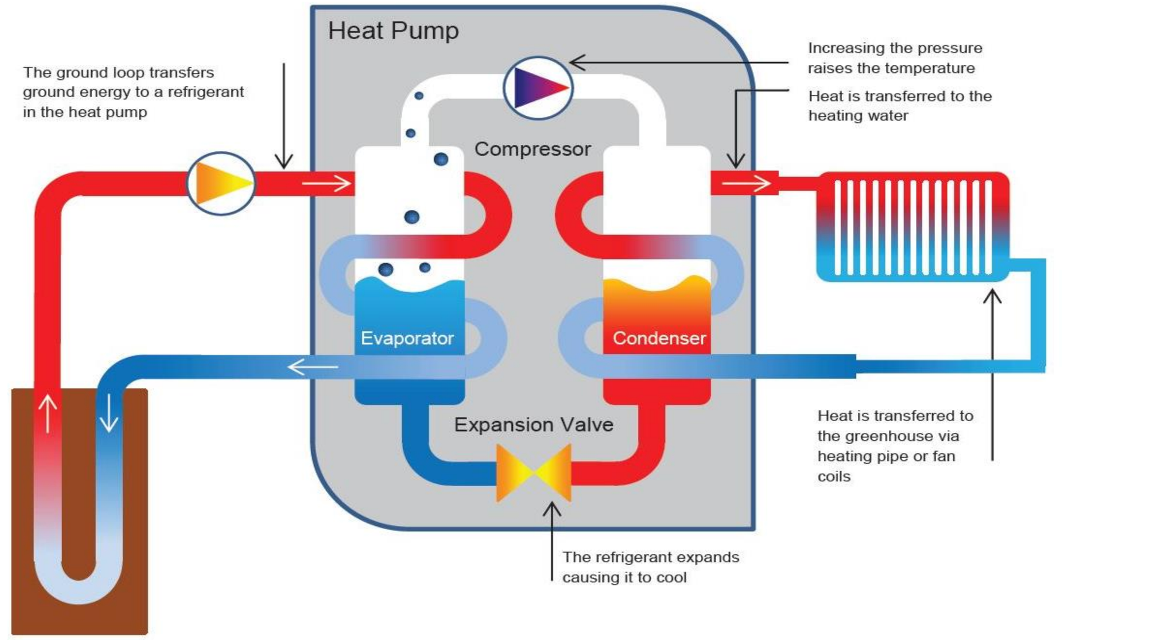
Source: www.epa.gov

Concentrated solar power (CSP) is an approach to generating electricity through mirrors. This technology uses mirrors to reflect and focus sunlight onto a thermal receiver. The intense CSP energy heats up the fluid (heat-transfer fluid or HFT) in the receiver to high temperatures. This heat or thermal energy is used to turn a turbine and thus generate electricity (source: **energysystems.com**). The thermal energy contained in the fluid can be stored for later use. CSP energy also has direct industrial applications in water desalination and food processing. Concentrated solar power also has a high energy output, which makes it suitable for large-scale electricity generation. One of the main drawbacks is its high capital and maintenance costs. CSP installations require significant upfront investments, Additionally, the technology is still relatively new, and there's a lack of experienced professionals in the field.

The ground as a heat source

Another source where heat can be absorbed from is the ground. This is done by geothermal or ground-source heat pumps. They can heat or cool and supply even hot water to a home by transferring heat to or from the ground. They can operate in any climate because of the earth's constant underground temperature. The temperature rises in about 25-30 degrees/km of depth near the surface in most of the world due to the heat flow from the much hotter mantle. The effect of weather, the sun and season only reach a depth of roughly 10-20 m (**www.energy.gov**). Geothermal heat pumps need some electricity to run. They can be connected with solar panels. Heat pumps are very efficient.

How a ground source heat pump works



Source: www.archive.ahdb.org.org.uk

Air or water as heat source

The air surrounding us or water close by could by a source of heat. Heat pumps are able to absorb this heat and transfer already existing heat from the environment into a building. They mainly use the energy stored in the groundwater, or air for space heating, domestic hot water, ventilating, and cooling. There are water-water heat pumps and air heat pumps. They are very efficient. They work well with well-insulated buildings; distribution systems working at low temperature, i.e. underfloor heating and large radiators and higher temperature of the heat source (soil, groundwater or air) (source **ehi**). But they need some electricity to run.

The heat pump challenge

A large number of heat pumps are using fluorinated gases or F-gases as refrigerant. Fluorinated gases are man-made gases that are used in for example heat pumps and switchgear. These F-gases are used sparsely but they are extremely powerful: F-gases are between 1,400-22,800 more potent than CO2. Today, F-gases account for 2.5% of EU greenhouse gas emissions. The heat pump sector has pledged to support the shift from F-gases to natural refrigerants whenever possible and has already achieved significant progress in the monobloc outdoor unit segment. The current EU regulation aims to reduce F-gas emissions by two thirds of the 2014 level by 2030.The European Commission is targeting a reduction of F-gas emissions by 90% until 2050 compared to 2015. On 21 July 2023 EU deal on F-gases was delayed. Three issues created the stalemate: heat pumps, switchgear – the boxes that regulate electrical flow – and Annex IV, which sets out rules for when various kinds of products will be banned. There are already heat pumps on the market with natural refrigerants with lower global warming potential (GWP) such as air, CO2, ammonia, hydrocarbons and water).

Global warming potentials: F-gases in orange

Gas	GWP (AR4, 100yr)
CO_2	1
Methane	25
Nitrous Oxide	298
HFC-134a	1,430
R-404A (HFC blend)	3,922
R-410A (HFC blend)	2,088
HFC-125	3,500
PFC-14	7,390
SF_6	22,800

Source: climate.ec.europe.eu

Rest heat

Rest heat is the heat released as a by-product of industrial processes or electricity generation. In many cases this heat is wasted. However, using rest heat is becoming more common. It contributes to more efficient energy use, reducing the need for energy sources. There are several ways to use rest heat. Heat recovery refers to the process of reclaiming a portion of the energy wasted by the use of heating, venting and air conditioning systems. Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. Cogeneration is a more efficient use of fuel or heat, because otherwise-wasted heat from electricity generation is put to some productive use. This involves the concurrent production of electricity or mechanical power and useful thermal energy (heating and/or cooling) from a single source of energy (source: energy.gov). Combined heat and power (CHP) it is a highly efficient process (over 80%) that captures and utilises the heat that is a by-product of the electricity generation process. The electricity could be generated from renewables as well. By generating heat and power simultaneously, CHP can reduce carbon emissions by up to 30% compared to the separate means of conventional generation via a boiler and power station. The heat generated during this process is supplied to an appropriately matched heat demand that would otherwise be met by a conventional boiler.

Another way to use rest heat is in district heating. District heating involves generating heat in a centralized location and then distributing it to residences, businesses, and industry in a local area. District heating is the distribution of heat from large scale generation and waste heat sources around large areas, usually within cities, connecting community heating schemes together. Typical central energy sources: power stations, EfW (energy from waste), gas fired combined heat and power units, biomass combined heat and power, industrial heat pumps, solar/geothermal sources. The primary benefits of district heating are threefold: lower energy costs, environmental (through the reduction in carbon emissions) and security of supply. According to the IEA in 2022 district heat production remained relatively similar to the previous year, meeting around 9% of the global final heating need in buildings and industry. District heating offers great potential for efficient, cost-effective and flexible large-scale integration of low-emission energy sources into the heating energy mix.

Create heat from electricity

The creation of heat from power or converting electrical energy into heat is called in short power-to-heat. Renewable energy sources can produce electricity and this electricity is converted into heat. There are several ways to do that and the applications differ for households and industry. For households the main heaters are electric resistance heaters (baseboard heaters, panel heaters, underfloor heating and wall heaters), infrared heaters or a combination (electric fireplaces).

Underfloor heating provide radiant warmth that is transmitted upwards from the floor. Baseboard and panel heaters are convection heaters and electric fireplaces are a combination of infrared radiation and convection.

For industrial applications there are the following forms of heating: resistance heating, induction heating, infrared heating, microwave heating, graphene heating and carbon nanotube heating. We now explain in short, these different industrial heating technologies (source: ee-ip.org).

Resistance heating is a common heating technology that involves passing an electric current through a material with high resistance, such as a metal wire or an alloy. They are controlled with a thermostat. The resistance generates heat, which is used to heat up the material. Resistance heating can be used for temperatures up to 1200°C. Induction heating is the technology that involves using electromagnetic induction to heat up a material. It is a non-contact technique for heating metals or other electrically conductive materials by electromagnetic induction. An alternating magnetic field is generated around the material, which induces an electric current in the material, producing heat. Induction heating can be used for temperatures up to 2500°C. Infrared heating uses infrared radiation to heat up a material. The infrared radiation is absorbed by the material, which heats up. Infrared heating can be used for temperatures up to 1000°C. Microwave radiation is used to heat up a material. Microwaves are non-ionizing radiation. This means they don't alter atoms and molecules and damage cells like ionizing radiation does. The microwaves penetrate the material and excite the molecules, producing heat. Microwave heating can be used for temperatures up to 3000°C. Graphene heating is a relatively new heating technology that involves using graphene to generate heat. When an electric current is passed through graphene, the resistance of the material generates heat. Graphene can be used in electric underfloor heating but also in industrial processes. Graphene heating can be used for temperatures up to 2000°C. Carbon nanotube heating is another new heating technology that involves using carbon nanotubes to generate heat. When an electric current is passed through carbon nanotubes, they heat up, generating heat. Carbon nanotube heating can be used for temperatures up to 3000°C.

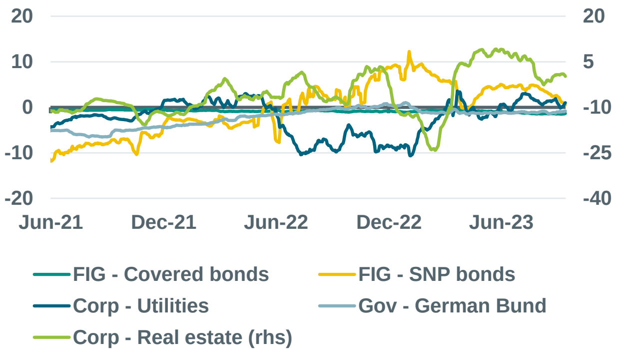
Conclusion

Heating is mostly generated by burning fossil fuels. To reduce emissions and even reach net-zero in 2050 for heating is an enormous challenge. There are several ways to approach this. We can continue to burn something. But then the fuel or mass needs to be replaced by a more sustainable and low emission fuel or mass. The availability and the production of these fuels are still limited and not enough to replace fossil fuels. There are also other sources to generate heat namely the sun (via thermal solar collectors), the ground, air and water (via heat pumps). The possibilities are available but the costs are still high compared to burning fossil fuel. There is another challenge concerning heat pumps. It is likely that the EU will further strengthen the regulation to reduce the use of fluorinated gases (F-gases) which are used as a refrigerants in heat pumps. This could hamper the roll out and/or acceptance of heat pumps. Rest heat is another source of heat that is mainly been wasted. The potential of rest heat for industry and district heating are substantial. Last but not least renewable electricity could be converted into heat for household and for industry.

ESG in figures

ABN AMRO Secondary Greenium Indicator

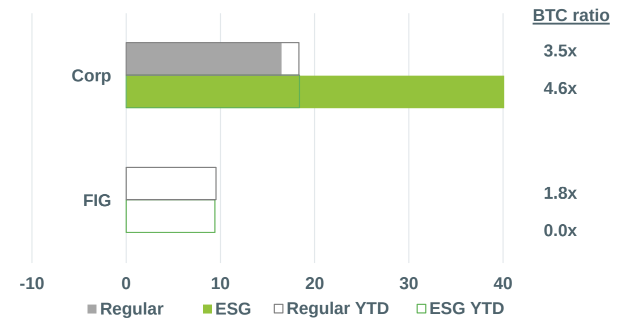
Delta (green I-spread – regular I-spread)



Note: Secondary Greenium indicator for Corp and FIG considers at least five pairs of bonds from the same issuer and same maturity year (except for Corp real estate, where only 3 pairs were identified). German Bund takes into account the 2030s and 2031s green and regular bonds. Delta refers to the 5-day moving average between green and regular I-spread. Source: Bloomberg, ABN AMRO Group Economics

ABN AMRO Weekly Primary Greenium Indicator

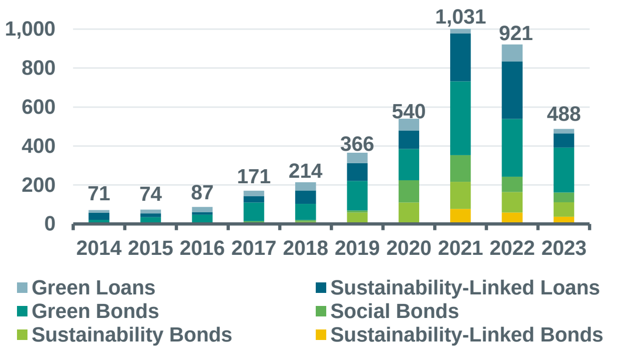
NIP in bps



Note: Data until 14-09-23. BTC = Bid-to-cover orderbook ratio. Source: Bloomberg, ABN AMRO Group Economics

Sustainable debt market overview

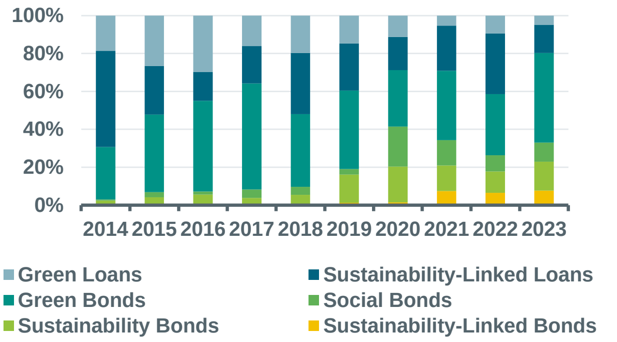
EUR bn



Source: Bloomberg, ABN AMRO Group Economics

Breakdown of sustainable debt by type

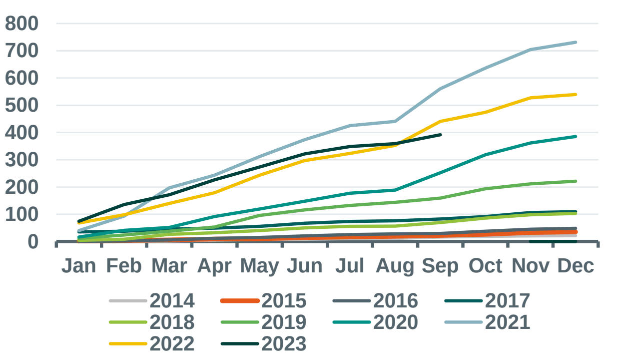
% of total



Source: Bloomberg, ABN AMRO Group Economics

YTD ESG bond issuance

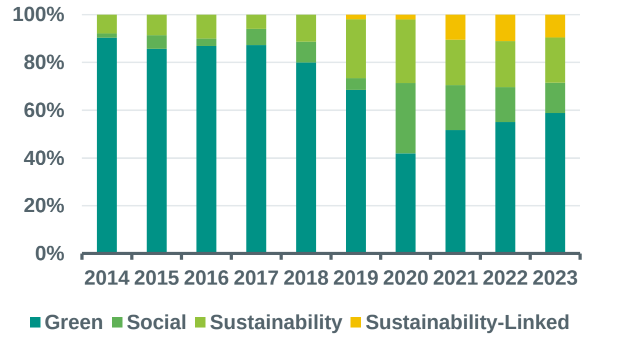
EUR bn (cumulative)



Source: Bloomberg, ABN AMRO Group Economics

Breakdown of ESG bond issuance by type

% of total

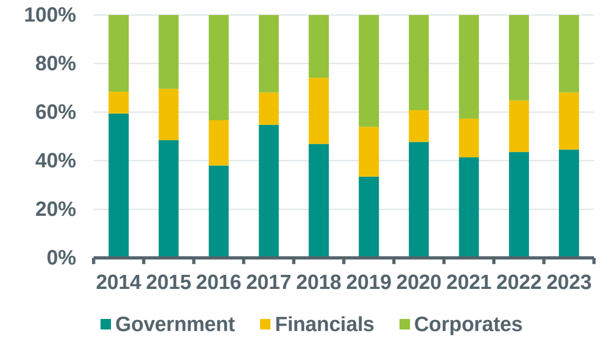


Source: Bloomberg, ABN AMRO Group Economics

Figures hereby presented take into account only issuances larger than EUR 250m and in the following currencies: EUR, USD and GBP.

Breakdown of ESG bond issuance by sector

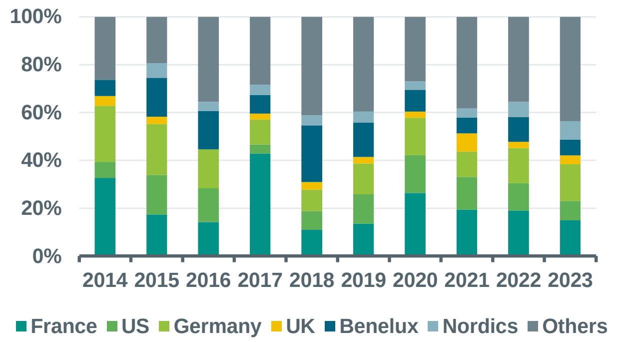
% of total



Source: Bloomberg, ABN AMRO Group Economics

Breakdown of ESG bond issuance by country

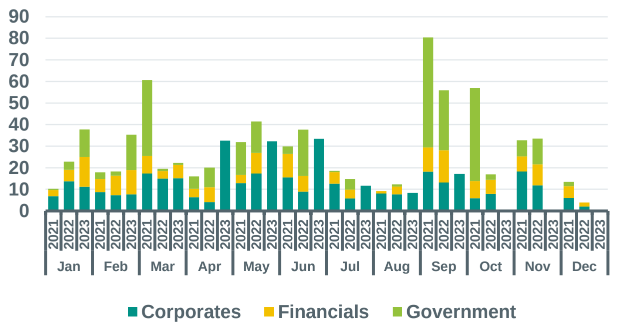
% of total



Source: Bloomberg, ABN AMRO Group Economics

Monthly Green Bonds issuance by sector

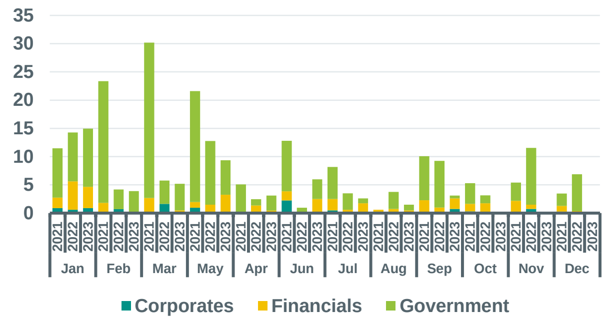
EUR bn



Source: Bloomberg, ABN AMRO Group Economics

Monthly Social Bonds issuance by sector

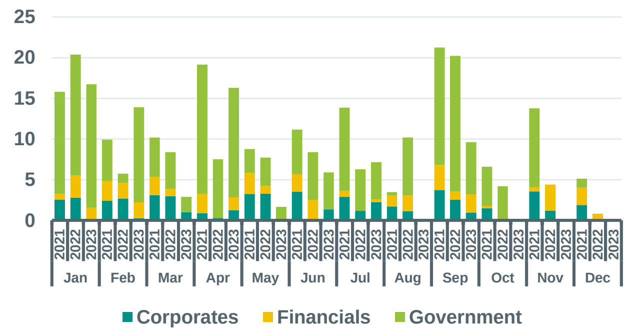
EUR bn



Source: Bloomberg, ABN AMRO Group Economics

Monthly Sustainability Bonds issuance by sector

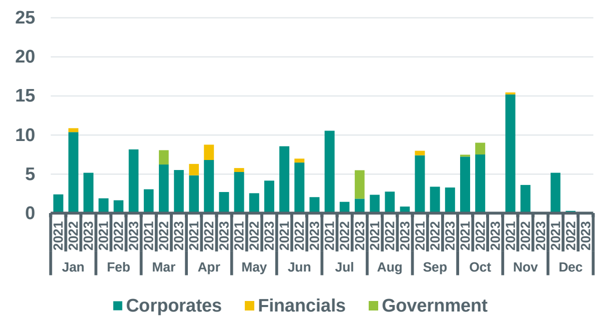
EUR bn



Source: Bloomberg, ABN AMRO Group Economics

Monthly Sust.-Linked Bonds issuance by sector

EUR bn



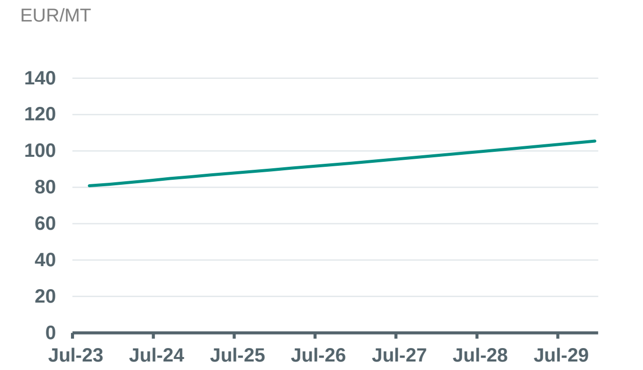
Source: Bloomberg, ABN AMRO Group Economics

Figures hereby presented take into account only issuances larger than EUR 250m and in the following currencies: EUR, USD and GBP.

Carbon contract current prices (EU Allowance)

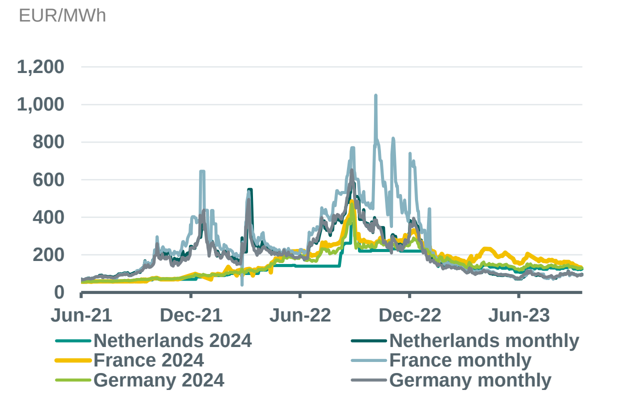
Source: Bloomberg, ABN AMRO Group Economics

Carbon contract futures curve (EU Allowance)



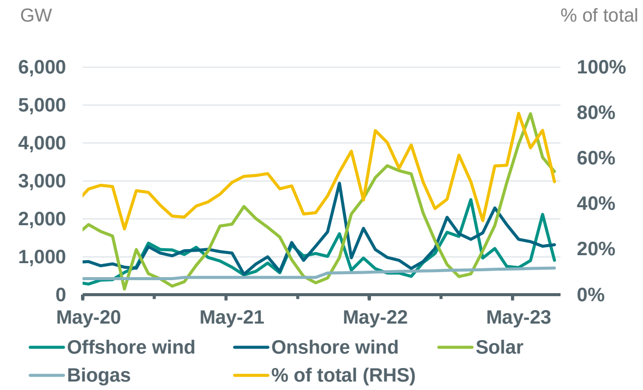
Source: Bloomberg, ABN AMRO Group Economics

Electricity power prices (monthly & cal+1 contracts)



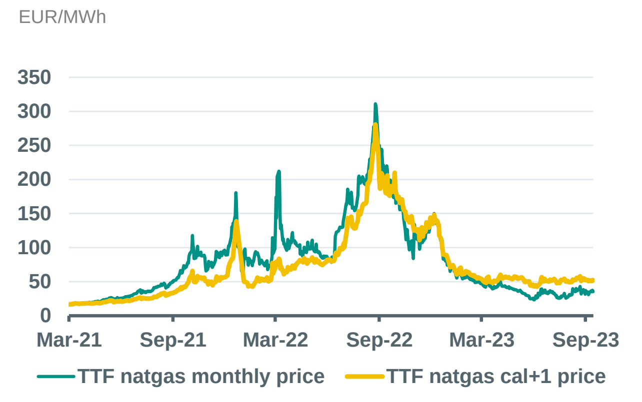
Source: Bloomberg, ABN AMRO Group Economics. Note: 2024 contracts refer to cal+1

Electricity generation from renewable sources (NL)



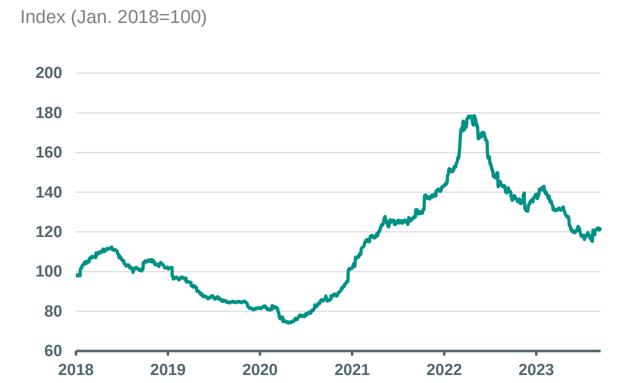
Source: Energieopwek (Klimaat-akkoord), ABN AMRO Group Economics

TTF Natgas prices



Source: Bloomberg, ABN AMRO Group Economics

Transition Commodities Price Index



Note: Average price trend of 'transition' commodities, such as: corn, sugar, aluminium, copper, nickel, zinc, cobalt, lead, lithium, manganese, gallium, indium, tellurium, steel, steel scrap, chromium, vanadium, molybdenum, silver and titanium. Source: Refinitiv, ABN AMRO Group Economics

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