Paper and board welcome $C0_2$.Ø

Story 2050 | The VNP CO_2 roadmap

VNP

PŐYRY

1 Preface

How do you get a large number of people, companies and technologies simultaneously to different places at different times? Our consultant, Pöyry, has associated this with a 'metro roadmap', an ingenious system of tracks and timetables. The Paper and Board Welcome CO_2.Ø roadmap shows our destiny: Terminus 95 (95% CO_2 reduction by 2050). Different strategic tracks with stations and junctions lead the way to Terminus 95. Together with Pöyry, we have analysed the tracks and the associated preconditions for implementation. If one thing becomes clear with all the information in this report, it is that it is important to start your journey today, and have a clear goal in mind. Only then will you be in time and be among the winners of the future.

We are aware that CO_2.Ø means a paradigm shift: following a transition period, a new way of producing paper and board will emerge. The metro roadmap shows the steps, actions, technologies and breakthroughs involved. For this journey, we need the support of many. We challenge scientists, students, technology developers, and basically anyone with bright ideas to come up with solutions. In addition, cooperation with the government and synergy with other sectors will be indispensable, as we know that the infrastructure of future energy systems – heat, H2, CO_2 and green electricity – will be key.

Over the past few years, the Dutch paper and board industry has achieved major savings in materials and energy. The results of the MEE energy covenant show the impressive progress the sector has made in terms of energy savings in processes, promoting circularity and chain optimisation. Under the inspired leadership of Royal VNP, paper and board companies are working together on the innovation agenda 'Creating Sustainable Fibre Solutions' on promising 'green' ideas and concepts, with a focus on implementation.

In the Netherlands, 18 companies (21 mills) produce world-class paper and board: board for the packaging market, graphic paper for magazines, brochures, leaflets, specialties and sanitary paper. The main raw material used is recycled paper (85%). Alternative fibres, such as tomato stems, grass, Miscanthus and beverage cartons, are also becoming increasingly popular.

The sector employs 4,000 people.

Gerrit Jan Koopman
Director of the Netherlands Paper and Board Association (VNP)

2 Contents

3 Management Summary

Without ambition, nothing is achieved. And without pragmatic assessment, ambition may go overboard. And again, nothing is achieved.

To continue on a track of long-term continuous improvement, VNP commissioned a roadmap for the Dutch paper industry, with the aim of reaching the governmental goals of 49% CO_2 reduction by 2030 and 95% CO_2 reduction by 2050. The result is a CO_2 'metro roadmap', which describes the steps needed.

There is no silver bullet in the paper industry – no single solution that cuts through all complexity and achieves this extremely ambitious goal. Instead, thanks to long-standing development work, there are numerous 'tracks' that together may achieve the desired result. In 2017, the industry emitted a 'cake' of 1,052 kilotons of CO_2. By 2050, 95% of this cake will have to be 'eaten' in order to reduce it to no more than 5% of 1990 emissions. This means maximum emissions of just 85 kilotons. To reach this ambitious goal, the roadmap examines three types of solutions of different complexity.

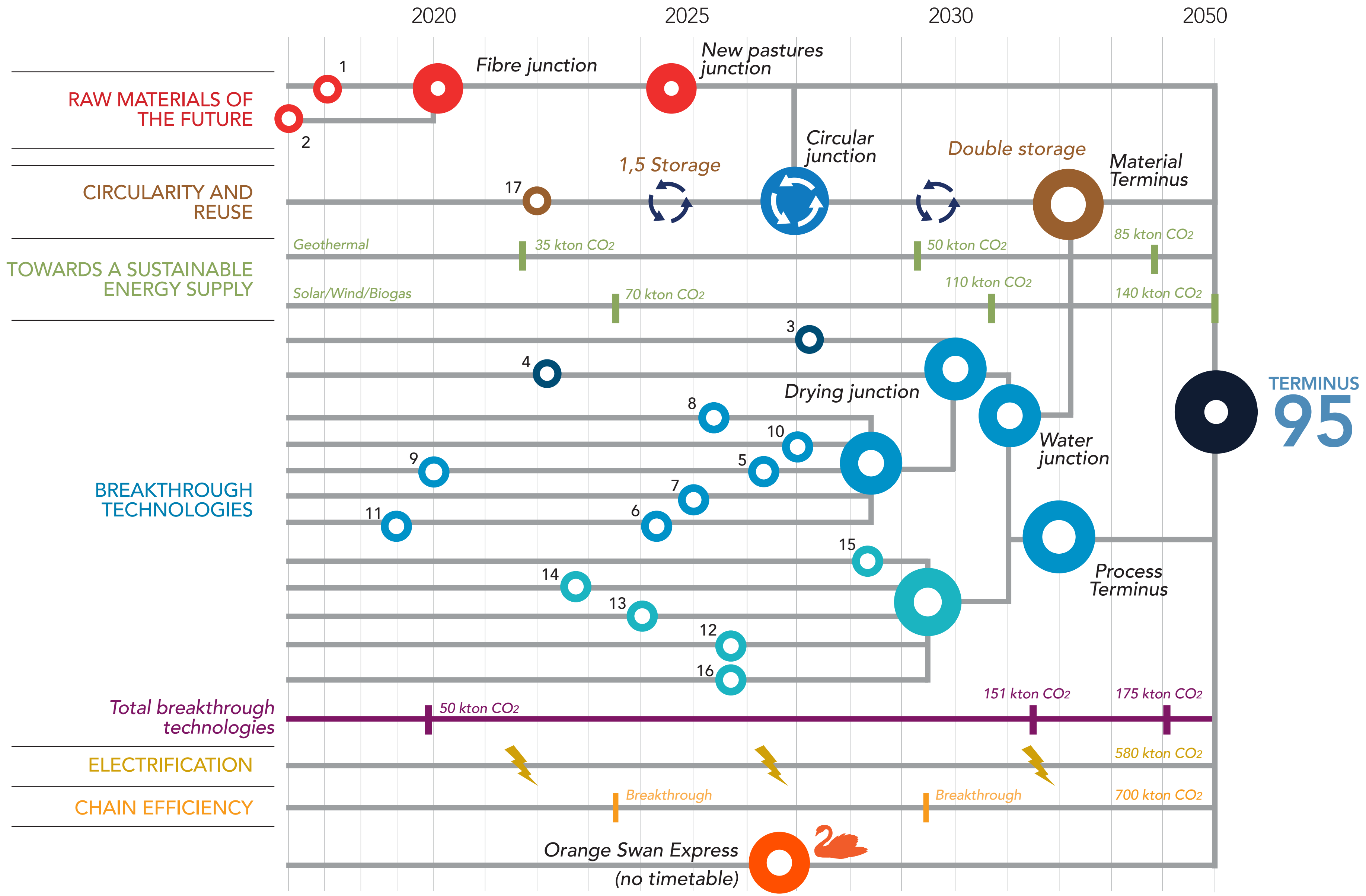
First, ***local*** solutions focus on the production sites and look at future raw materials, circularity, sustainable energy and breakthrough production technology.

Second, ***faster*** tracks consider chain efficiency (savings along the whole paper chain) and electrification of heat-driven processes.

And third, the ***ultra-high*** speed track consists of new technologies and solutions that may arise between now and 2050, but which no one can currently predict. We call this track 'the orange swan'. It is part of the roadmap, but it has no values, and the targets should also be reachable without it. It is simply a reminder that there is a large, unpredictable element we cannot assess or count on.

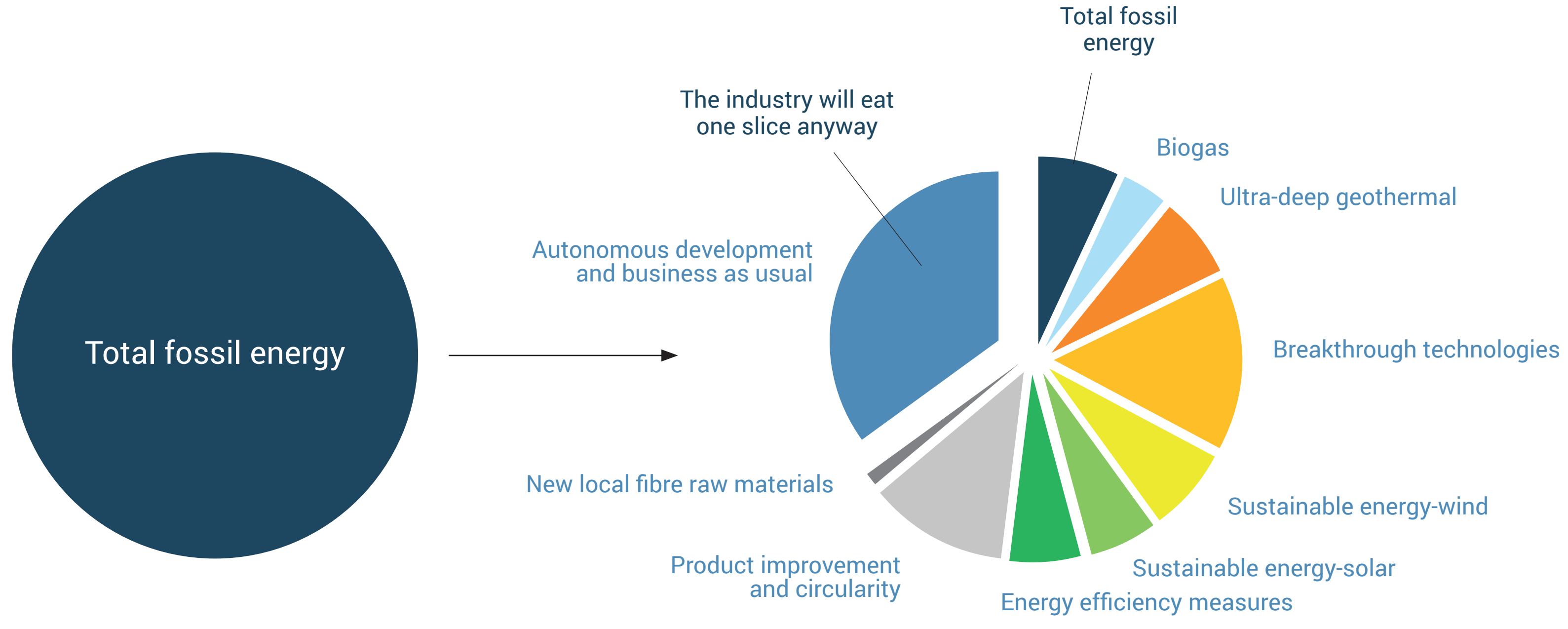
All solutions proposed are graded from low-hanging fruit (business as usual), medium- and high-hanging fruit to, finally, radical innovation.

As a special perspective, we also examined the importance of recycling in CO_2 storage. At the current recycling rate of about 85%, combined with assumed losses and recycling loops, about 3.4 tons of CO_2 are bound in one ton of recovered paper. By increasing the recycling rate, decreasing process losses and increasing the time the fibre spends in the loop, we can increase the level of CO_2 storage. The importance of this should be properly understood.



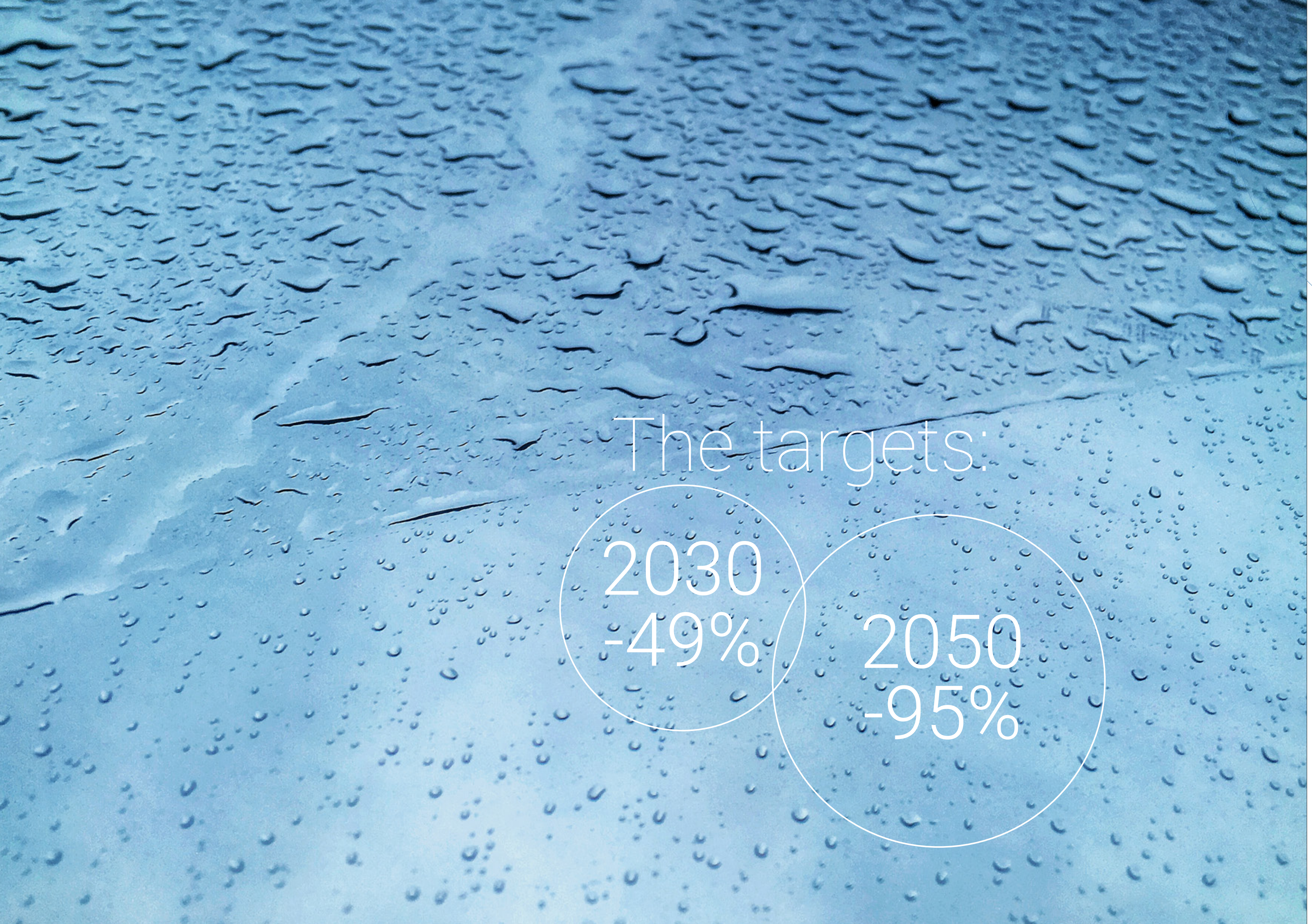
In 2017, the fossil energy CO_2 cake was 1052 ktons

In 2050, what is left from the cake is 85 ktons of fossil energy CO_2



The roadmap reaches the ambitious targets, but there is a cost, obviously. We have assumed autonomous development to be 'business-as-usual', entailing no extra cost. Still, our assessment arrives at a total capital expenditure net present value of EUR 4.5 billion, about EUR 140 million per year. This is a burden that the industry cannot bear in normal competitive circumstances. The playing field for Dutch mills in international competition will need to be level, or solutions will not be developed.

However, with the right incentives, support strategy and collaboration across Europe, a low-carbon, even more sustainable paper and board sector is possible. There is indeed a future, but success is not self-evident.



4 Introduction
How to achieve a demanding target?

4.1.1 A demanding target
For 2050, the Dutch government has set a target of reducing CO_2 emissions by 95% compared to 1990, and for 2030, this target is 49%. The Paper and Board industry in the Netherlands wishes to contribute to this effort. What are the steps we need to take in the coming 5 to 10 years to move in the right direction and at the right speed? The sector is already actively looking for possibilities within the framework of its Innovation Agenda 'Creating Sustainable Fibre Solutions'. Several studies and projects are being carried out focused on using more sustainable raw materials and energy.

In this study, VNP's vision, targets, innovation directions and conditions are brought together in *a dedicated roadmap that will guide the industry towards the 2030 and 2050 targets on time.* It describes the relevant roads that need to be taken, as well as the actions and conditions required to accelerate developments.

4.1.2 Creating Sustainable Fibre Solutions (CSF)
CSF is VNP's Innovation Agenda. With icon projects, priority is given to the issues with the highest impact. The icon team members are employees of VNP member companies.

CSF 1 Raw materials of the future
With new fibre sources from fibre-rich residual flows and sustainable crops, local cycles are closed in a sustainable manner and CO_2 emissions in the chain are prevented

CSF 2 Towards a sustainable energy supply
The current energy supply of paper production can be made sustainable by using CO_2-neutral energy sources, such as biogas, ultra-deep geothermal energy, solar and wind energy, as well as biomass and hydrogen.

CSF4 Breakthroughs in paper production
The drying process, the largest energy consumer in our production process, will need to change radically. This will require drastic changes in the way water is removed. Alternatively, in the future, paper may be produced without the use of water.

CSF5 Circularity and reuse
The more paper and board that is in circulation and the longer the recycling loop, the more CO_2 remains stored. The aim is to further increase the circularity of our products and thus contribute to reducing the concentration of CO_2 in the atmosphere.

VNP's vision
We believe that circularity and carbon neutrality will be key issues in the years to come. They will shape our industry's future. If you do not share this vision, you will not see the changes in your surroundings, at least not in time. For the future of our sector, it is important that we see, believe and act on these changes; only then will we belong to the winners of the future. If you look around, you realise that only a minority really believes in this message. The majority would rather like to stay in the 'old' system: a linear and fossil economy. For us it is clear that this is an irresponsible route. We have to learn from nature and embrace the circular and carbon-neutral economy.

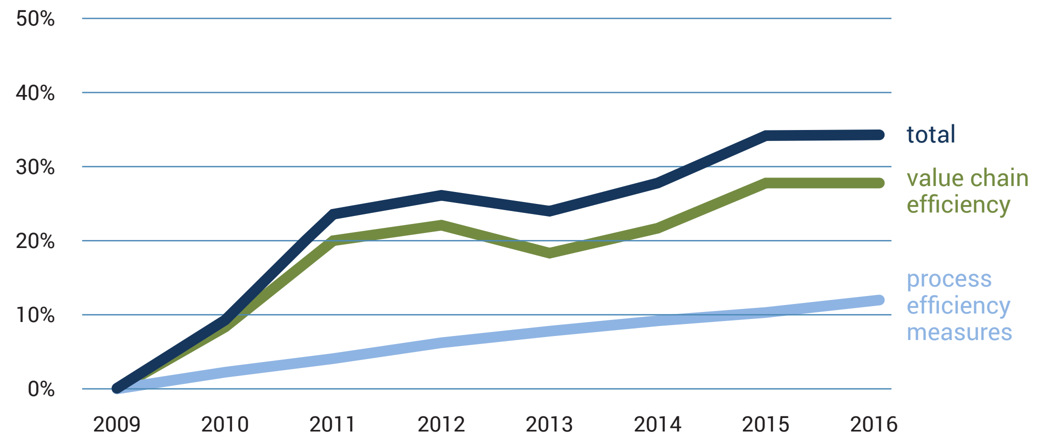
4.1.3 Energy covenants

Since the 1990s, government and industry have worked together in covenants on energy efficiency as part of the Dutch energy policy. In these covenants, the focus is on the reduction of energy consumption per unit of product or service. Every four years, companies draw up an Energy Efficiency Plan (EEP) and annual progress is monitored.

The plans of the paper industry describe measures on:
- process efficiency,
- energy mindset, management and good housekeeping
- value chain efficiency
- renewable energy

Between 2006 and 2016, most energy savings resulted from chain efficiency. This mainly concerned material savings, the optimisation of product functions and the reuse of products.

FIGURE 1 | **Energy savings**



4.2 Industry at a crossroads

From a policy, technological development and innovation perspective, paper industry companies are at a crossroads:
- Companies operate in a globalised world, where the largest competitors have cost advantages in terms of labour, energy and raw material. The sector has to compete in terms of being ahead in efficiency and innovation.
- At EU level, the ETS revision has come to an end, and the preparatory work for its implementation is starting. The benchmark will be adjusted, the linear reduction factor will increase, free allowances will generally decrease, and the CO_2 price will rise.
- At a national level, the 2030 ambition of the Dutch Government is set at 49% reduction of GHG emissions, and the circular economy policy in the Netherlands is taking shape in the national resource agreement.

The paper sector was and is uniquely placed to address the priorities in terms of climate change, circular economy, resource efficiency, and environment.

Roadmap
- *Keep track of progress towards the 2030 and 2050 goals*
- *Give advice on additional tracks to be started up*
- *Allow prioritisation on strategic directions when needed*
- *Secure a high level of support in the industry to secure rapid implementation*

However, in order to reach the important CO_2 targets on time, many parallel developments will need to progress faster than they are doing right now. This roadmap will support individual companies in the choices they will need to make and the activities they will need to perform. It also elucidates the conditions and circumstances required to allow rapid progress. It supports VNP in keeping track of its progress with regard to its CO_2 emission targets and in ensuring the necessary support, policy, funding and facilities.

4.3 Consciousness and inspiration

All stakeholders in the paper sector are fully aware of the importance of the end station and the huge transformation required to get there. However, taking the right routes is not self-evident. How can we ensure that the right routes are taken? And how can we ensure that these routes are as smooth and pleasant as possible, indeed leading to a happy ending – or, rather, a happy starting point of the next journey?

The aim of the roadmap is therefore to inspire the entire sector. Each individual company should be able to make its own choices and take the route that fits in with its individual ambitions and circumstances. The roadmap should ensure that, whatever route is taken, all companies will be fully supported by dedicated and knowledgeable experts, through collaboration with governments and other sectors, with research and technological breakthroughs, and by investments and the right infrastructure, all in a stimulating financial and legal landscape. Only if all companies feel inspired and are convinced that the routes are the right ones will the transformation be successful and the final destination reached.

The bookkeeping of CO_2 reduction

The English saying 'You can't have your cake and eat it, too' is relevant here. If we eat a cake, we will not have any cake left. If the paper industry reduces CO_2 emissions, CO_2 will disappear from its bookkeeping. This means that what the roadmap describes is a very serious effort to use technologies, available and not-yet-there, to truly eliminate CO_2 emissions. This will take effort and costs.

5 Scenarios

How much CO_2 to reduce?

5.1 The race to 2030 and 2050

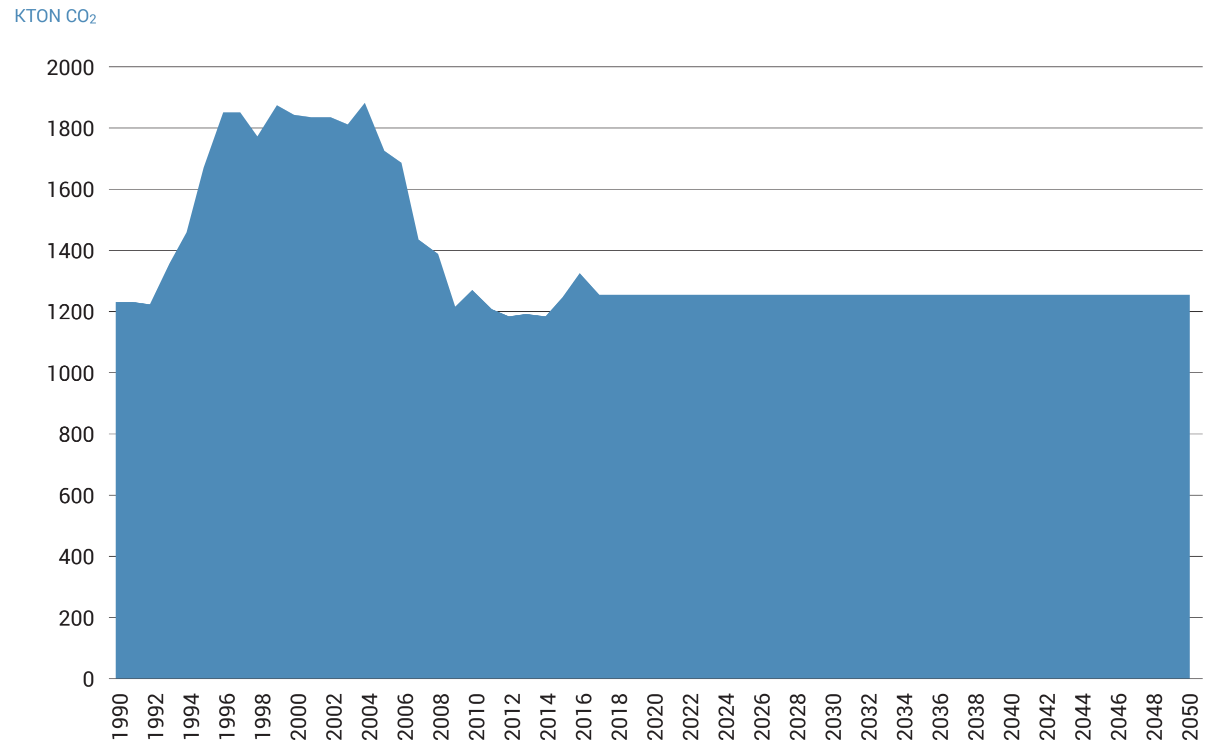
For 2050, the target is to reduce CO_2 emissions by 95% compared to 1990. For 2030, this target is 49%. What are the steps we need to take in the coming 5 to 10 years to move in the right direction at the right speed?

5.2 The CO_2 baseline

We have a clear baseline: CO_2 emissions from 1990 to the present day (see Figure 2). Starting in the early 1990s, the Dutch paper industry experienced a decade of growth, leading to a significant increase in CO_2 emissions. At the beginning of the 21st century, the industry started taking energy efficiency measures, bringing CO_2 emissions back to the level of 1990, while maintaining production capacity. If we freeze emissions at their current level of 2018, and keep the 1990 level of 1.2 Mt/a as a base, the cake we have available to slice up and eat can be represented as shown in Figure 2.

This cake does not disappear in one sitting. It will have to be eaten over time, in reasonable slices. To this end, a *divide and share* strategy will be necessary.

FIGURE 2 | **The CO_2 baseline scenario**



5.3 The wedge-track strategy for reducing CO_2

In our scenario, we combine the Carbon Mitigation Initiative's concept of 'stabilisation wedges' with specialised reduction strategies called 'tracks'.

(Stabilisation) wedge

A framework for understanding both the cuts in carbon emissions needed to avoid dramatic climate change, and the tools already available to do so

Tracks

A strategic tool to reach carbon emission reductions

5.4 Reducing CO_2 - one wedge at a time

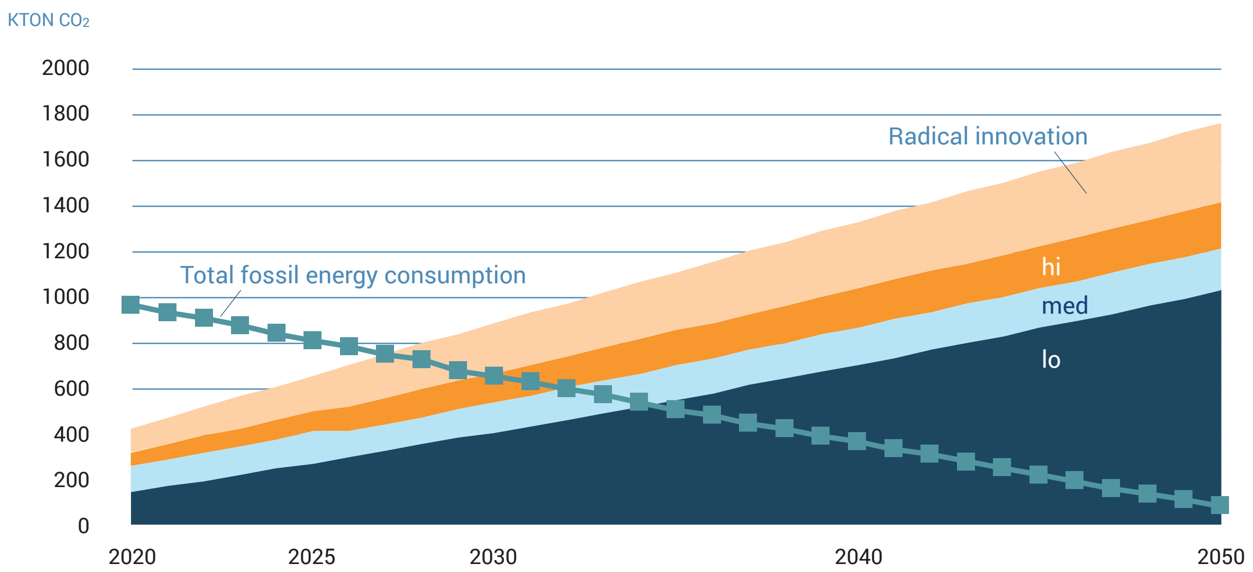
We start with the 1.2 Mt/a emission cake from 1990 and start eating away one slice at a time. Wedges can be divided by difficulty, as shown in Figure 3. By assessing each technology in terms of its feasibility, we can form an estimate of the costs and the achievability of the targets.

Although nothing is easy, autonomous development is the wedge with the lowest investment in effort, time and money. We assume that a certain amount of reduction will be the result of continuous daily improvements. Autonomous development therefore represents the lo wedge.

At the opposite end of the spectrum is radical innovation: the sort of breakthroughs necessary if a very tough promise is to be fulfilled.

Between the lo and radical wedges lie two degrees of difficulty: medium (med) and high (hi). Both these wedges are characterised by the need of extraordinary effort beyond business-as-usual. The difference between them is determined by the technologies and efforts required. Having a 'beyond-high' wedge of radical innovation is a calculated statement: something quite extraordinary will be needed to achieve a reduction of 49% by 2030 and 95% by 2050.

FIGURE 3 | **Reducing CO_2 wedge by wedge**



5.5 Conclusions

The CO_2 emissions 'cake' can only be 'eaten' piece by piece, not all at once or using a single approach.

To understand the task and needs, we need to divide the CO_2 emissions 'cake' into wedges of different toughness: *autonomous development (lo), medium (med), high (hi) and radical innovation*.

At the same time, the tasks need to be divided into strategic tracks, which are related to efforts already in progress or envisaged by the Dutch paper industry, including breakthroughs in solar and wind power, for example.

6 The tracks

How to reduce CO_2 emissions?

6.1 The railway/metro visual - many tracks leading to the final destination

Getting many people from A to B by different means and with complicated schedules works well with railways in the Netherlands.

Similarly, cutting CO_2 slices into different strategic tracks is an exercise in getting many people, companies and technologies simultaneously to different places at different times – and with clear goals in mind. Since this type of visual has previously been associated with underground (metro) maps, we here present the concept of the 'metro roadmap' in the context of the reduction of CO_2 emissions.

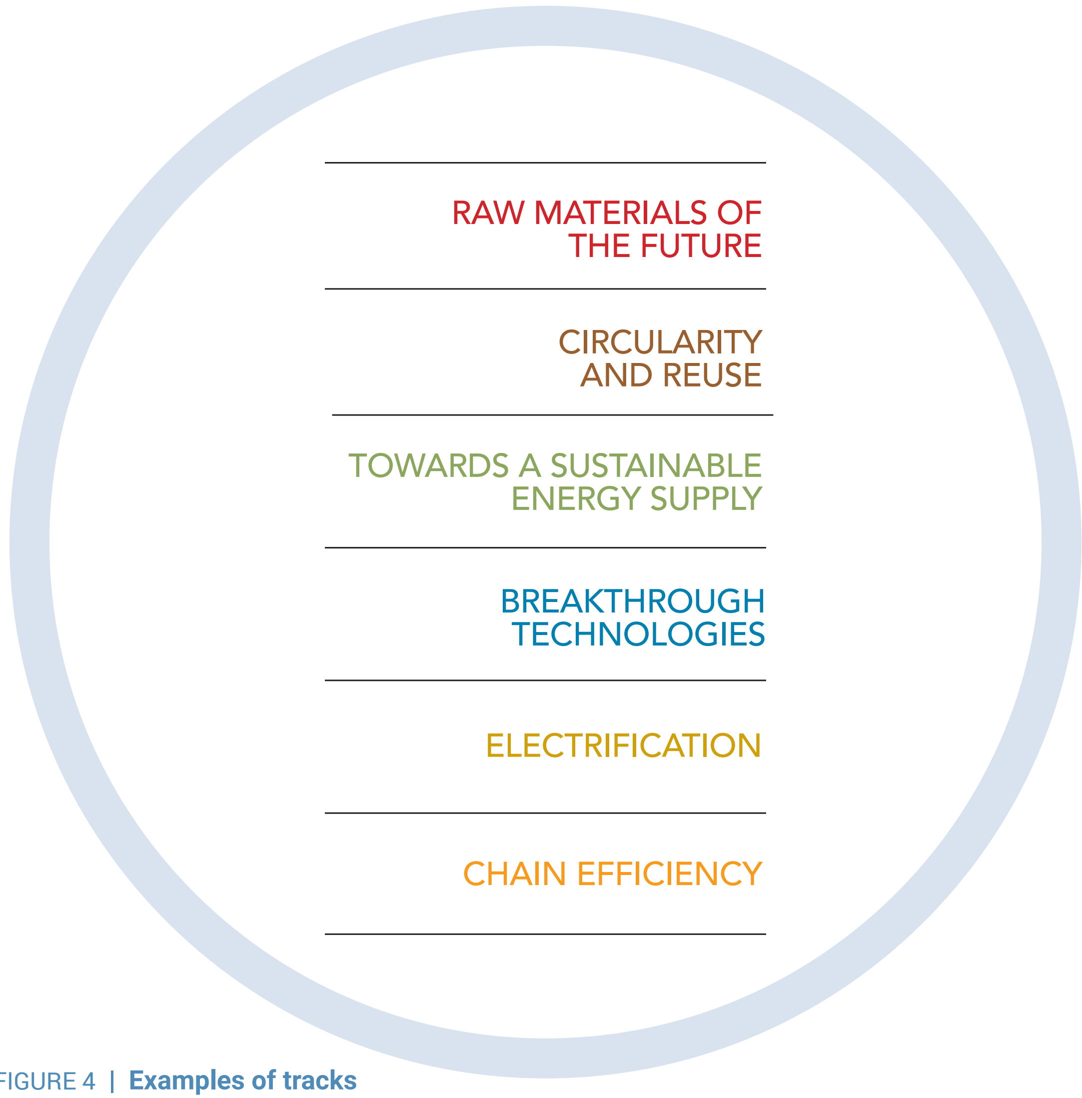


FIGURE 4 | **Examples of tracks**

6.2 The 2050 tracks for reducing CO_2

A track is a strategy for reducing CO_2. Travellers can follow a variety of tracks to reach their final destination. Tracks may use different trains that take different routes, all of which differ in speed and impact. Each company should be able to make its own choices and take the route that fits in best with its individual ambitions and circumstances. These choices may depend on their raw materials, product portfolio, regional situation and infrastructural developments (e.g., energy supply systems).

In Figure 4, the tracks are listed, linking them to work already done and currently being done by the Dutch paper industry. These activities are being performed within the framework of the VNP Innovation Agenda 'Creating Sustainable Fibre Solutions' (CSF). The CSF icon projects focus on the innovation routes with the greatest impact with regard to the sustainable use of raw materials and energy. The strategic plans of the CSF icon teams are used to analyse the potential of each track.

LOCAL TRAINS

The sector can reach its CO_2 targets by choosing those tracks that affect its direct CO_2 emissions at its production sites. This may involve making changes in raw materials, processes and energy supply, for example.

Raw materials of the future

New fibre sources from fibre-rich residual flows and sustainable crops make it possible to close local cycles in a sustainable manner, preventing CO_2 emissions in the chain.

Circularity and reuse

The more paper and board that is in circulation and the longer the recycling loop, the more CO_2 remains stored. The goal is to further increase the circularity of our products and thus contribute to the reduction of CO_2 concentration in the atmosphere.

Towards a sustainable energy supply

The current energy supply of paper production can be made sustainable by using CO_2-neutral energy sources, such as biogas, ultra-deep geothermal energy, solar and wind energy, biomass and hydrogen.

Breakthroughs in paper production

The drying process – the largest energy consumer in the paper production process – will need to change radically. This requires drastic changes in the way water is removed. Alternatively, in the future, paper may be produced without the use of water.

FAST TRACKS

The CO_2 'metro roadmap' of the Dutch paper sector is just a small link in a huge national and even global network. The impact of national technological and infrastructural choices on the speed of CO_2 savings in the paper sector is enormous. On the other hand, choices made by the paper industry may significantly affect the speed of CO_2 savings elsewhere. The overall aim should be to reach Terminus 95 as fast as possible – together!

Chain efficiency

With its innovations, the Dutch paper sector has frequently proven that it can achieve substantial CO_2 savings in the chain and in the environment. The sector will continue this successful approach in the coming decades. This will lead to more sustainable use of our products, symbiosis with the environment and fruitful collaboration with other sectors.

Electrification of heat-driven processes

Heat-driven processes can be converted into electrically driven processes. Actual reduction of CO_2 emissions requires expansion of the electricity grid with fully CO_2-neutral electricity production.

THE ULTRA-HIGH SPEED CONNECTION

The future cannot be predicted. Just as the success of smartphones was not foreseeable at the beginning of this century, we do not know whether unplanned technologies may be invented in the coming decades that may significantly accelerate our journey. The 'Orange Swan Express' will welcome any traveller willing to take this ultra-fast track into the adventurous future.

FIGURE 5 | **The tracks to 2050**

ALL TRACKS TO TERMINUS 95

INDEX

RAW MATERIALS OF THE FUTURE
1 *Miscanthus*
2 Grass

CIRCULARITY AND REUSE
17 Circular mill

TOWARDS A SUSTAINABLE ENERGY SUPPLY
18 Geothermal
19 Solar/Wind/Biogas

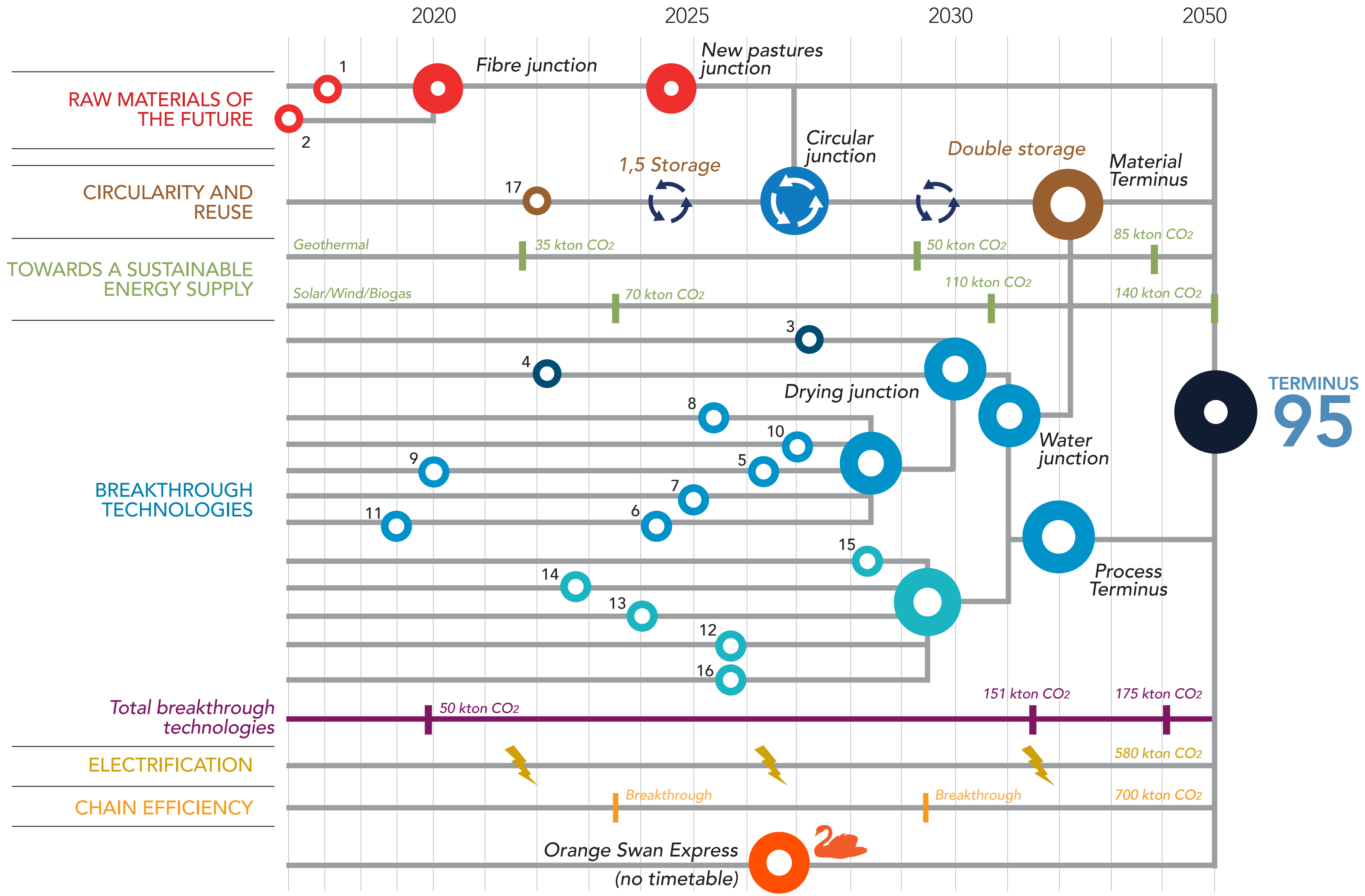
BREAKTHROUGHS IN PAPER PRODUCTION (WITHOUT WATER)
3 Alcohol as carrier
4 Foam forming

BREAKTHROUGHS IN PAPER PRODUCTION (DRYING)
5 Supercritical drying
6 Electrodewatering
7 Ultrasonic dewatering
8 Osmotic dewatering
9 Microwave drying
10 Hygroscopic drying
11 Superheated steam

BREAKTHROUGHS IN PAPER PRODUCTION (SIMPLIFICATION)
12 Dry formation
13 Cellulose solution-DES
14 Cross-linking
15 Supercritical solution
16 Solution spinning

ELECTRIFICATION OF HEAT-DRIVEN PROCESSES

CHAIN EFFICIENCY



6.3 The metro roadmap: map and traveller's guidelines

In the 'metro roadmap', all parallel tracks are connected, together leading to the final destination (Figure 5).

The traveller's reading guidelines are:

- The journey is complicated but well-coordinated, with many people, companies and researchers getting onto different trains at different times.
- The end station is *Terminus 95* (as in 95% CO_2 reduction).
- All tracks lead to *Terminus 95*.
- All tracks have stations. Some of these are key goals (e.g., reaching breakthrough drying technologies at the Drying junction), while others are milestones (e.g., reaching 50 kton CO_2 reduction on the breakthrough track)
- *Travellers are strongly reminded that, to get to Terminus 95, they need to board at the right stations early on!*

Dividing up the cake before eating it

No, we cannot eat our cake and have it, too. And reducing CO_2 emissions by 95% will not be a piece of cake, either. Trying to do it in one expensive bite will give massive economic indigestion. Instead, we will need to divide it and share it. As shown in the figure below, we need to find the right way to divide the cake of CO_2 and deal with it.

Finding a fair algorithm for splitting costs (or, literally, dividing the cake) is a popular application area for mathematicians and economists. Here, we have:

- *A part of the cake that will be eaten anyway, as the industry continues to work hard on reduction measures in its daily operations (autonomous development)*
- *Other parts representing different technologies/tracks*

We need to find the right way to split the cake, combining all available sensible means of reducing CO_2 emissions and developing new ones.

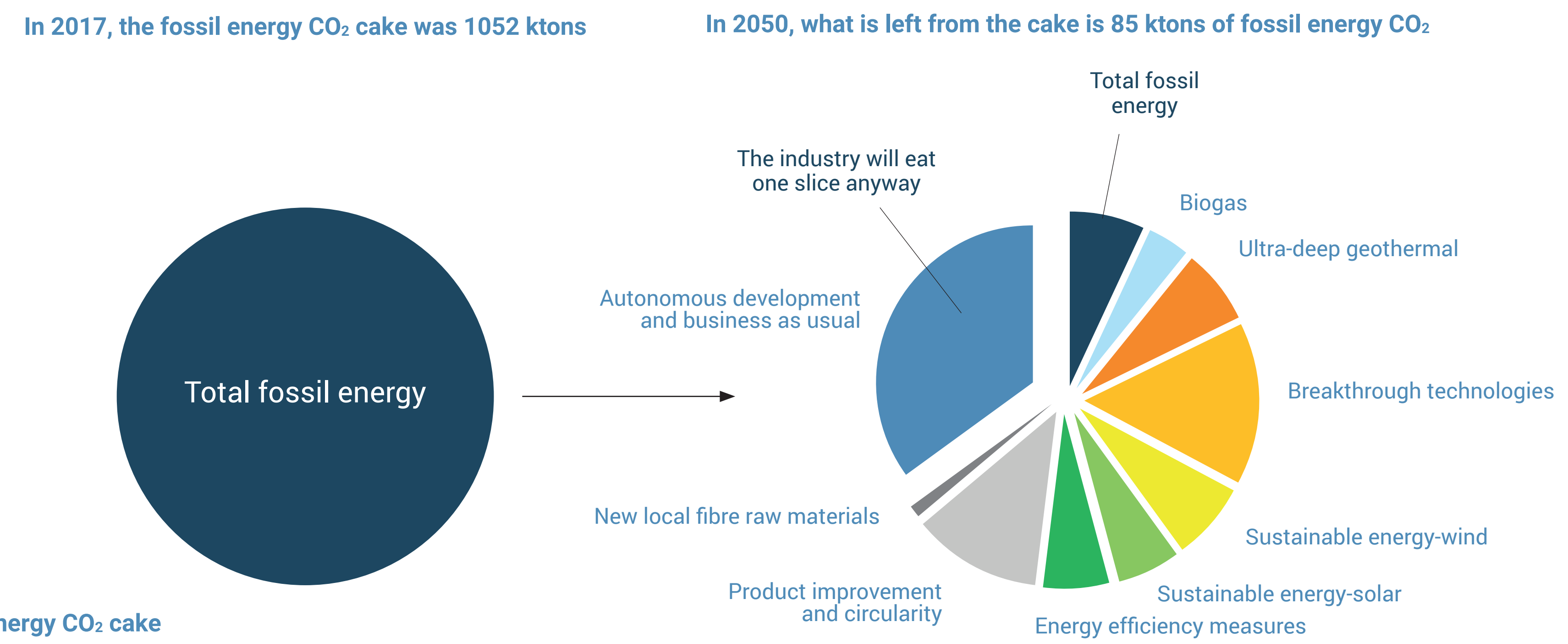
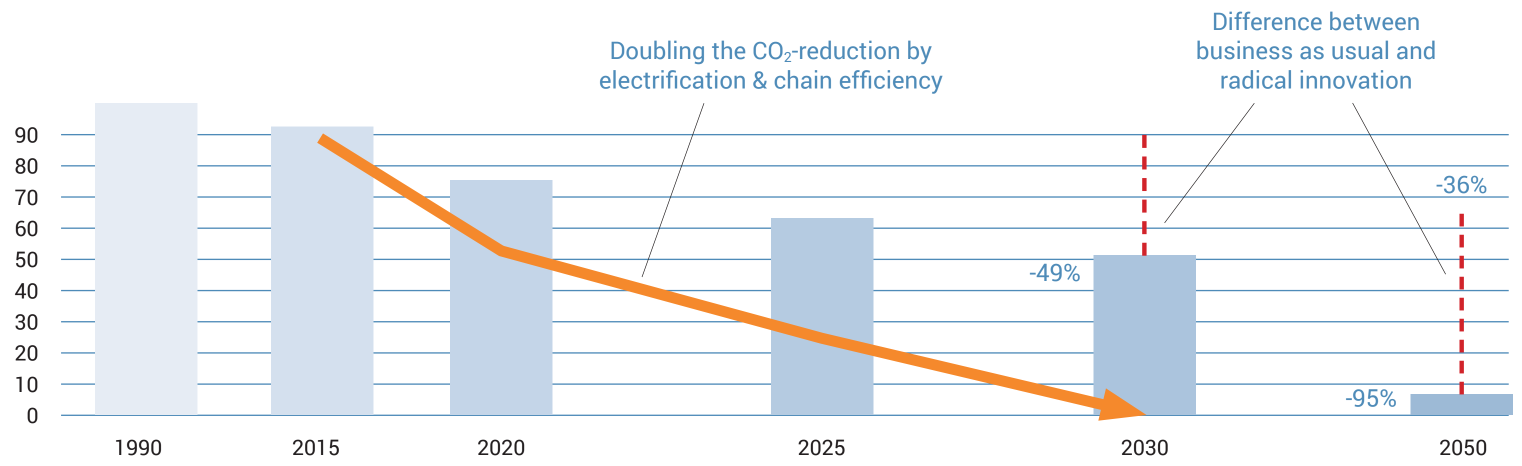


FIGURE 6 | **The fossil energy CO_2 cake**

FIGURE 7 | **Reducing CO_2: roadmap scenario**



6.4 Scenario outcome - the contribution of each of the tracks

In the main scenario for the roadmap, the industry succeeds in reaching the targets (Figure 7). This is done by using all tracks. If the fast tracks - chain efficiency and electrification - are also included, the reduction potential of the industry will increase by a factor two.

6.4.1 The alternative fibres track

In the alternative fibres track, two projects are especially notable:

- Grass
- Miscanthus (elephant grass)

The key undisputable benefits lie in:

- Shorter distances for fibre raw material transport
- Renewable 2G biomass entering the recycling loop

In addition, this track may lead to:

- New properties for products, resulting from new types of fibre mixtures
- Additional benefits (e.g., related to soil)

Miscanthus has an interesting additional property. It is currently being tested to keep Schiphol Airport safer. Geese constitute an increasing hazard for aircraft landing and taking off. Miscanthus is a type of grass that geese do not like. It thus helps to create 'goose-free' zones.

Direct benefits for the CO_2 emission of paper production processes are low to zero. Incentives for using alternative fibres should come from chain efficiency, with CO_2 emissions being avoided in harvesting and transport, or with CH_4 emissions being avoided in composting or digestion.

6.4.2 The product improvement and circularity track

Although recycling never disappeared in real life, it seemed to be absent in the public discussion until it reappeared as the circular economy. In the land of M.C. Escher, there should of course be an Escherian raw materials economy, with technology and practice enabling seemingly impossible feats.

However, improving products and fibres and valorising side streams in the industry can play a role in reducing CO_2. In chapter 7, we will take a closer look at recycling and the possibilities it offers for CO_2 storage – one key aspect that is often misunderstood.

6.4.3 The solar track

VNP's 2050 scenario starts with reporting on energy production from onsite solar panels from 2016 onwards. It is estimated that, in 2030, solar energy will produce 450 TJ, and this number is expected to reach 648 TJ in 2050. In terms of the reduction of CO_2 emissions, it is estimated that the total amount of CO_2 emissions saved will reach 25 kton in 2030 and 35 kton in 2050. The calculation of CO_2 emissions is based on the assumption that electricity generation from fossil resources uses natural gas. In addition, measures to be taken for solar energy production are generally considered to be part of the 'medium' slice of the cake (see Figure 3). In other words, medium-effort measures must be taken to reach the above-mentioned goals. Solar technology is already available, but new and more efficient technologies will need to be developed to reduce the use of metals, to save space and to increase output.

CASE STUDY

A solar panel comprising a number of solar cells is a photovoltaic system. Photovoltaic solar panels generate electricity through sunlight. Onsite solar panels can therefore be used to generate green electricity for the mills, with rooftop areas being suitable for this purpose. Even though photovoltaic solar energy (PV) still needs further development and R&D, it is considered to be one of the most promising renewable technologies. The table below presents the key figures estimated for onsite solar panel installations (without SDE+ subsidy).

Key figures:

Total available roof area (incl. correction) (m2)	*599,675*
Total estimate number of solar panels	*300,000*
Capacity per panel (Wp)	*285*
Price per panel (EUR)	*250*
Annual production (GWh/y)	*78*
Yearly CO_2e savings (kton)	*41*
Investment (MEUR)	*75*
Price of CO_2 (EUR investment/ton CO_2 saved)	*1,813*

6.4.4 The wind track

As in the case of solar panels, VNP's 2050 scenario for wind power starts by reporting on energy production from onsite wind turbines from 2016 onwards. Wind power is estimated to produce 580 TJ in 2030 and about 900 TJ in 2050. In terms of the reduction of CO_2 emissions, it is estimated that the total amount saved in 2030 will reach about 35 kton in 2030, and 50 kton in 2050. Again, similar to solar panels, measures to be taken for electricity generation from onsite wind turbines will largely be part of the 'medium' slice (see Figure 3). Wind power is also a readily available and maturing technology. According to the Global Wind report released by the Global Wind Energy Council (GWEC), wind power technology is successfully competing in the marketplace against traditional power generation technologies. Nevertheless, wind power technology still needs technological advances in order to reach higher efficiencies and higher outputs, while reducing, amongst other things, the use of rare metals. In addition, public opinion in the Netherlands with regard to wind parks on land will be crucial for further large-scale deployment in the future.

CASE STUDY

Wind turbines convert kinetic energy from the wind into mechanical energy and then into usable electrical energy. The Dutch government set a target of 6,000 MW of onshore wind power by 2020. An average wind turbine has a capacity of 2 to 3 MW, which means that the Netherlands will need 1,000 to 1,500 new onshore wind turbines. Wind and solar power tend to complement each other. This is due to the fact that in most places, during the winter months, the wind is stronger, with low availability of sunshine and vice versa for the summer months. Onsite wind power can therefore be used together with solar power or on its own for green electricity generation. The table below presents the key figures estimated for onsite wind turbine installations.

Key figures:

On site generation, VNP scenario (GWh)	*250*
Number of 3MW turbine on site	*38*
Electricity produced (for a 3 MW turbine) (GWh)	*6,6*
Yearly CO_2e savings (kton)	*132*
Investment (MEUR)	*133*
Price of CO_2 (EUR investment/ton CO_2 saved)	*1,008*

6.4.5 The ultra-deep geothermal track

VNP's 2050 scenario assumes that energy production from ultra-deep geothermal energy starts from 2016 onwards. Geothermal energy is estimated to produce 975 TJ in 2030, and 1650 TJ in 2050. In terms of CO_2 emission reductions, the total amount saved is estimated to reach 55 kton in 2030 and slightly over 90 kton in 2050. In terms of measures to be taken, ultra-deep geothermal energy is considered to be fully in the 'radical innovations' slice (see Figure 3). Even though geothermal energy has already been in use in the Netherlands for the past 10 years, ultra-deep geothermal energy requires drilling deeper than 4 km, while drilling currently goes no deeper than 2 to 3 km.

CASE STUDY

Ultra-deep geothermal energy (UDG) is a way of using heat from deep layers in the earth where temperatures are above 130°C. Heat from UDG can be used either for power generation or it can be used directly. The UDG project in the Netherlands is run by the Ministry of Economic Affairs and Climate (EZK) and Energy Management Netherlands (EBN). As a result of the cooperation between EZK, EBN, TNO and seven other market parties, test drillings for the extraction of ultra-deep geothermal energy in various parts of the Netherlands are currently being executed and planned.4 The table below presents the key figures estimated for ultra-deep geothermal energy.

Key figures

Max. subsidised load hours	*6,000*
Total thermal production (MWh)	*172,800*
Yearly CO_2e savings (kton)	*90,9*
Investment (MEUR)	*67*
Price of CO_2 (EUR investment/ton CO_2 saved)	*738*

6.4.6 The energy efficiency track

In the paper industry, the energy efficiency track has played a major part in energy savings since 2003, thanks to the 'VNP Energy Transition in the Paper Chain' programme, combined with national benchmarks and energy efficiency plans. This work continues, but most of the low-hanging fruit has already been harvested.

CASE STUDY

Heat pumps are an attractive alternative for producing steam without emitting fossil carbon dioxide. They use the heat from the environment or a reservoir to raise the temperature. Heat pumps need to be combined with a higher-temperature reservoir, powered by, for example, geothermal energy, solar energy or waste heat. Heat pumps are currently under development for temperatures above 80°C. The attractiveness of heat pumps lies in their high level of efficiency. They are much more efficient than direct electric heating. The table below presents the key figures of a heat pump system supplying steam of up to 160°C, starting from ground water of 10°C.

Key figures

CAPEX equipment only (W/thermal output)	*1,3*
CAPEX including installation (W/thermal output)	*2,4*
Capital costs (EUR/GJth)	*10,3*
Energy costs (EUR/GJth)	*7,9*
CO_2 (EUR/GJth)	*0,0*
Total costs (EUR/GJth)	*18,2*

6.4.7 The breakthrough track

With regard to breakthrough technologies, it is worth noting that:

- The use of water consumes a lot of energy (and hence leads to CO_2 emissions).
- Wetting raw material and then drying it again is the main source of energy consumption in paper production. The proportion varies from slightly below 50% to about 65%, depending on the grade.
- So, *reducing the amount of water that needs to be removed or reducing the amount of energy needed for drying* are key ways to reduce energy consumption and hence CO_2 emissions.

The VNP innovation icon team 'CSF4 Breakthroughs in Energy Efficiency' has gathered a list of potential technological solutions for 'waterless papermaking' or 'water removal without evaporation'. This is summarised in a special report, called the 'CSF4 Breakthrough Technology Roadmap – Exploring breakthrough technologies for the papermaking industry'. Reading this report is highly recommended, as it provides a deeper understanding of possibilities identified.

Most of the key breakthroughs therefore revolve around either new drying methods (e.g., supercritical drying, microwave drying) or 'less water or waterless' processes (e.g., foam forming or alcohol as a carrier). The methods identified are currently at varied levels of technology readiness (TRL), with likewise varying costs and impact.

6.4.8 The electrification track

If there is enough renewable zero-CO_2-emission electricity available to be purchased from the grid, electrification will, of course, be a means of reducing CO_2. However, experience shows that it cannot be assumed that all of Europe will automatically be CO_2 neutral, with limitless carbon-neutral electricity being available for every purpose. Therefore in the underlying scenario, electrification has been included as an additional element which will further reduce CO_2 and will contribute to demand side management and flexibility.

6.4.9 The value chain efficiency track

During work related to the Energy Transition, the paper industry has created a large portfolio of projects that connect topics and players, offering interesting results that touch on a variety of sectors. Similarly, for this roadmap, the measures taken in the paper chain by the paper industry will also affect various sectors outside the industry, such as chemicals, petrochemicals, machinery, retail, consumer electronics, media, printing, agro, food, cosmetics and, of course, the energy sector.

An analysis of various projects across the paper chain brings to light an additional impact of 35-45% in the value chain.

6.5 Conclusion

Using a 'metro map' analogy, the timetable illustrates how the different tracks and means interact.

Each track represents a certain amount of CO_2 which it is estimated will be capable of being reduced. All individual tracks are further explained and illustrated in cases.

This timetable is clearly complex due to the amount of detail involved. It also provides a roadmap for reaching some very ambitious goals, up to 2050. However, it is *not a forecast*; nor does it offer *a detailed breakdown of current and future practical* measures at every mill.

What is more, the 'Orange Swan Express' may make a welcome appearance, allowing an accelerated journey towards the terminal.

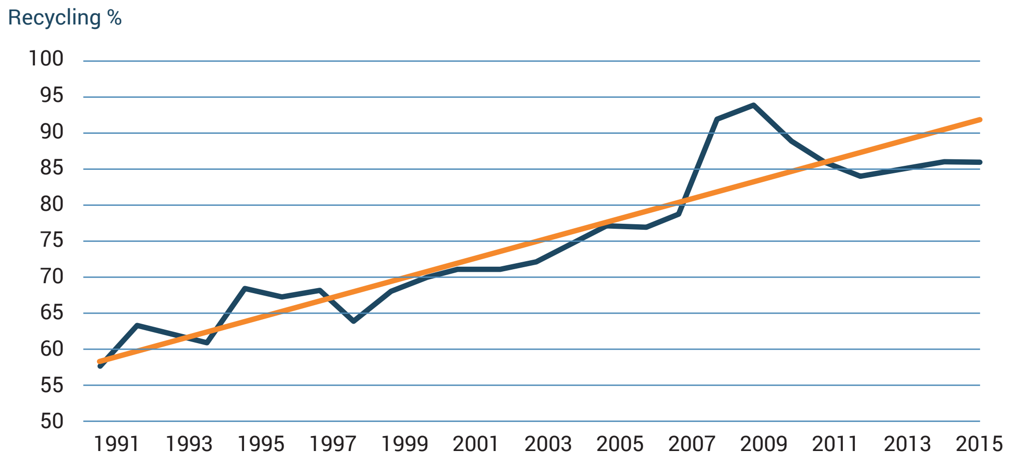
7 Recycling

How to increase the CO_2 storage capacity?

7.1 The significance of recycling

It has been observed that, although a single human can multitask, global opinion can only focus on one thing at a time. This limitation on the part of global opinion is unfortunate, since an emphasis on climate change and CO2 at one point could lead to an almost complete amnesia as regards recycling. However, recycling is reappearing under the new name of the 'circular economy'. This is making it relevant again, even though it is still unclear to many people to what extent recycling could play a key role in, for example, CO_2 storage. The Dutch paper industry is a world leader in recycling, and as Figure 8 shows, progress since 1990 has been exceptional.

FIGURE 8 | **Recycling rates in The Netherlands 1991-2015**



Calculating the carbon and CO_2 equivalent content

To calculate the CO_2 equivalent stored in wood pulp and recovered paper, certain things have to be taken into account. The calculation is as follows:

Wood usually contains just under 50% carbon. Carbon (C) has a molecular weight of 12. Oxygen (O) has a molecular weight of 16.

*CO_2, then, has a molecular weight of 12+2*16=44.*
This means the CO_2 equivalent for stored carbon is 44/12 = 3.67 times the amount of carbon.
Two materials are of interest here: wood pulp and recovered paper. Both these materials are often purchased by companies.

- *1 ton of wood pulp (mainly cellulose) contains 1.45 tons of CO_2-eq.[3]*
- *1 ton of recovered paper contains 1.29 tons of CO_2-eq.[4]*

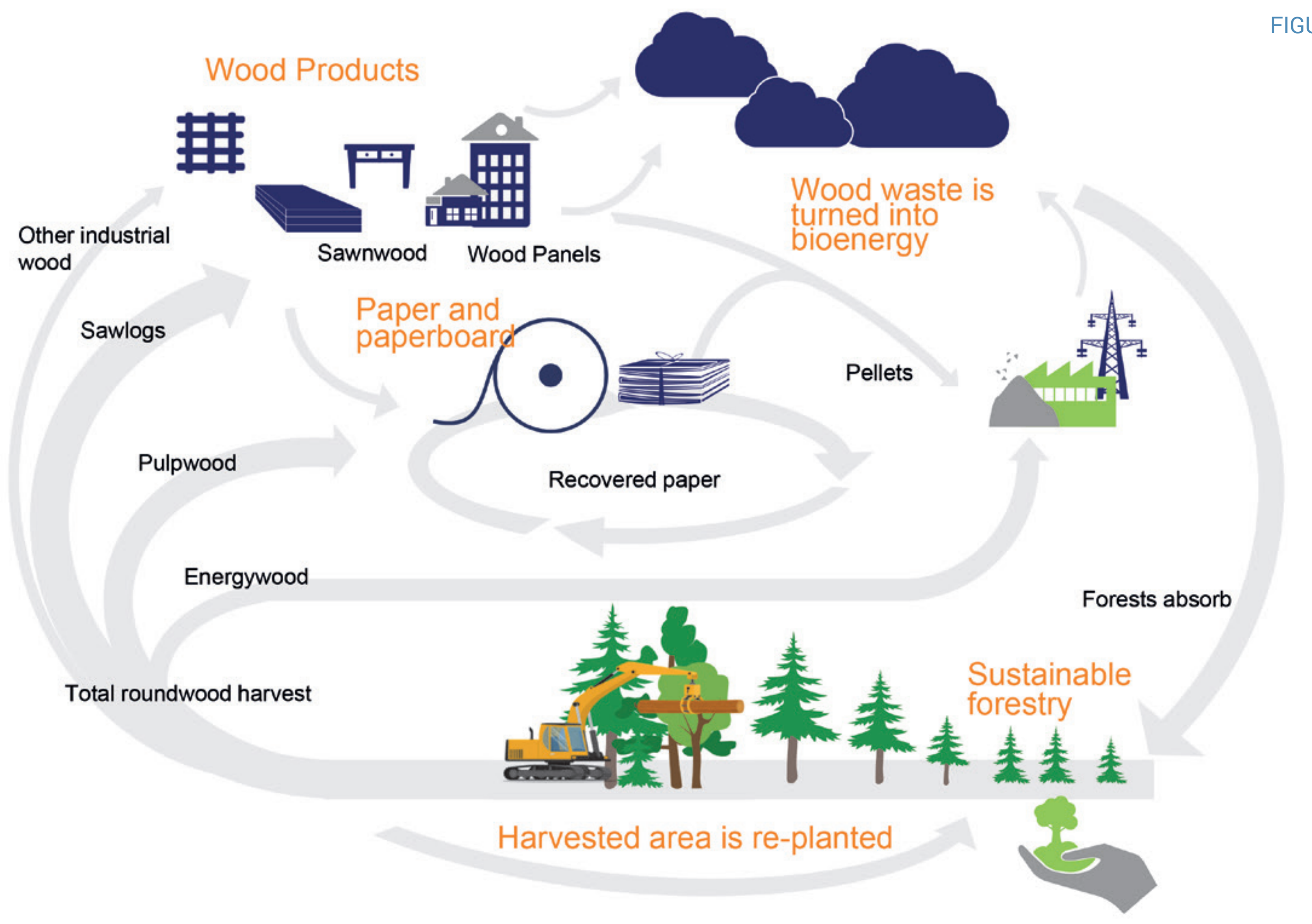
7.2 CO_2 storage

In the loop from raw materials to end use and back, carbon moves around a lot. Wood harvested from forests is used for wood products, paper, paperboard and other bio-based products, as well as for bioenergy, biochemicals, biofuels and biomaterials. The carbon that was stored in wood then transfers to carbon stored within these products.[3,4]

Carbon storage creates a 'carbon clockwork' of forests, recovered paper and paper products. Each of these products has a different rhythm (i.e., the time it takes to capture, use and deposit carbon). For example, a tree may be 70 years old when it is felled. On the other hand, recovered paper may have a circulation time of less than 30 days. All these different types of storage together make the clockwork go. In the paper industry carbon loop, carbon storage has a turning ratio from once in 70 years (trees) to up to 15 times a year (recovered paper). This means the slowest loop is more than 1,000 times slower than the fastest. And yet, it all works like a clockwork, where every part is essential to make the clock run.

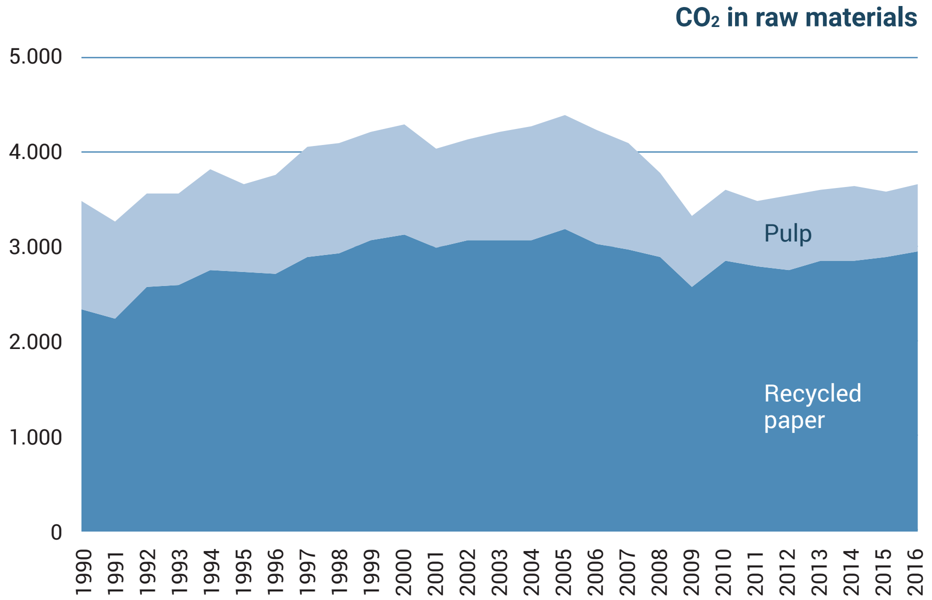
Inside the 'carbon circle' (i.e., the CO_2 loop), we see that there is a notable flow from industry to recycling, 66 Mt CO_2/a on a European level, and 3.6 Mt CO_2/a in the Netherlands.

FIGURE 9 | CEPI figure (torus)



[3] One ton of wood pulp consists of about 44% of carbon (compared to wood, pulp has more additional materials). To get the dry content, we multiply this percentage by 0.9. To calculate the carbon in 1 ton of wood pulp (dry), we use the following formula: 1*0.9*0.44=0.396. To get the CO_2-eq in 1 ton of wood pulp (dry), we multiply this by the coefficient 3.67 calculated above: 0.396*3.67 = 1.45. Hence, in wood pulp we have 1.45 tons of CO_2-eq.
[4] For recovered paper, there is a difference in wetness: to get to dry matter, we have to multiply by 0.801. So, for 1 ton of recovered paper, we get 1*0.801*0.44*3.67=1.29. So, 1 ton of recovered paper contains 1.29 tons of CO_2-eq.

FIGURE 10 | CO_2 in paper industry biofeedstock (kton)



7.3 CO_2 storage development so far

Essentially, this 'story' is about carbon and CO_2. Paper is rich in 'green', renewable carbon. As was calculated above, in each ton of wood pulp, there are about 1.45 tons of CO_2 equivalents. Per ton of recovered paper, we have about 1.29 tons of CO_2 equivalents. Based on the development of raw material used in the Dutch paper industry, this makes it possible for us to calculate the development of CO_2-eq. bound in the raw materials. As can be seen in Figure 10, we are at about the same level as we were in 1990: about 3.5 Mt of CO_2.

However, recycling is dynamic. The same ton of paper is used up to seven times. The process losses have been about 13%, and the recycling rate (as in Figure 8) make it possible to calculate how many times the same ton keeps CO_2 'in the loop'.

Using the concept of CO_2 equivalent, in Figure 11 we see the amount of virtual CO_2 stored over time in the recycling loop.

Calculating the virtual CO_2 storage in the recycling loop

*We start with a ton of paper: add 1 to the sum. About 85% is now recycled (as in Figure 8), and about 13% lost in the process: this gives 1*0.85*(1-0.13) = 0.74 t for the next loop of recycling.*

*Then, for the next round, we have 0.74 t*0.85*(1-0.13) = 0.55 t. Continuing this over six additional loops (which is a rule of thumb for practically usable recycling: fibres get broken and become unusable), we calculate the sum of the loops and get 3.21 tons.*

This means that 1 ton of recycled paper (with an 85% recycling rate and 13% process losses) is actually equivalent to 3.21 tons of paper. When you see a bale of recovered paper, it is actually 3.21 times its weight – taking into account the future uses of the same paper.

Hence, we have a virtual CO_2 storage in the recycling loop, which is 1.29 (the CO_2 equivalent based on carbon content) times the 'virtual amount of paper', which depends on the recycling rate, process losses and the number of possible recycling loops.

FIGURE 11 | **Virtual CO_2 storage in the recycled paper loop**

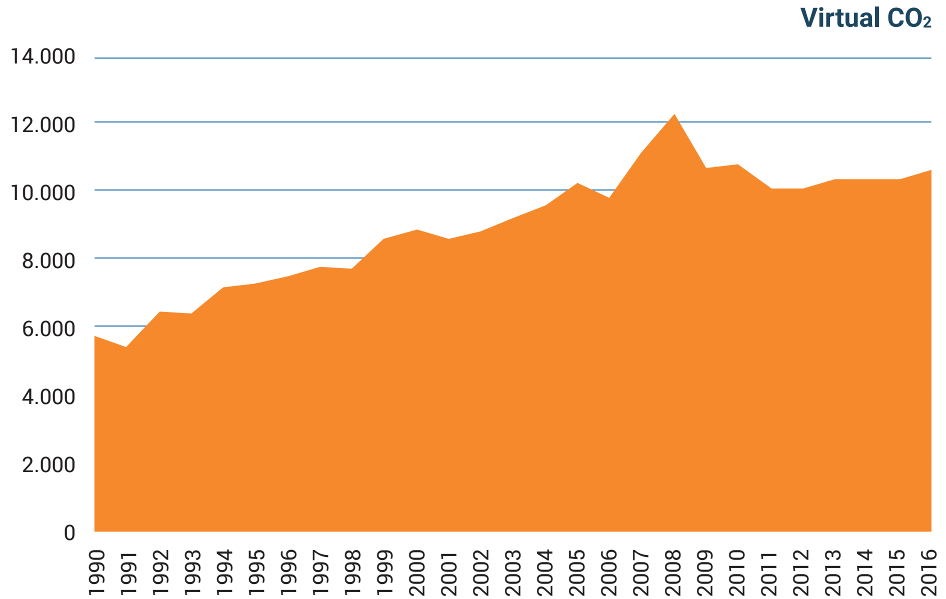
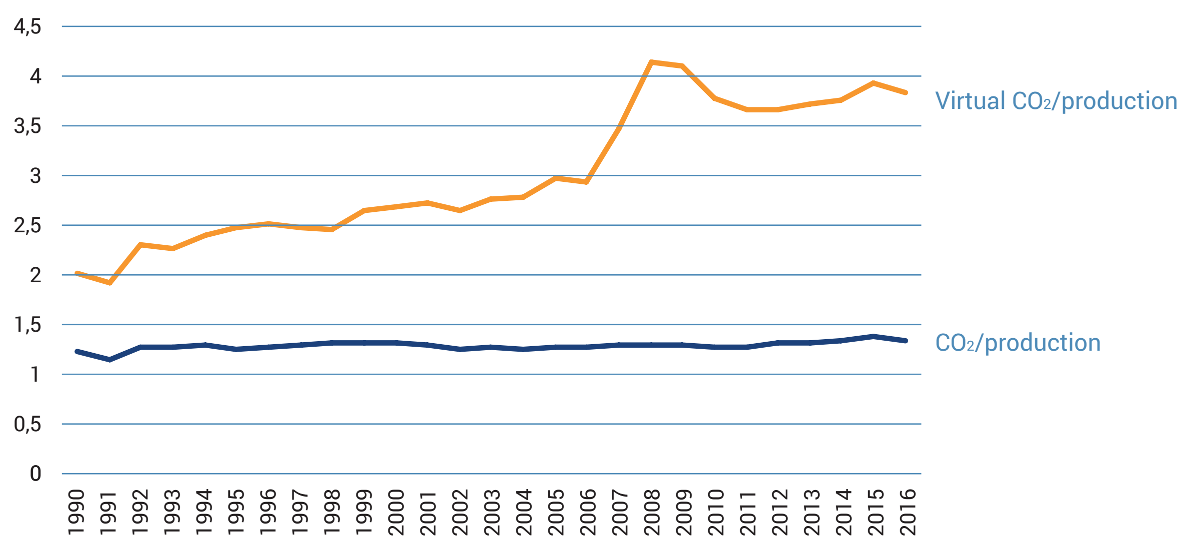


FIGURE 12 | **CO_2 and ‘virtual CO_2’: a virtuous, real development**



In Figure 12, we see the very real development of efficiency of CO_2 storage in the recycling loop. When we consider the development of the recycling rate, the storage per ton has doubled since 1990.

7.4 Growing the CO_2 recycling storage

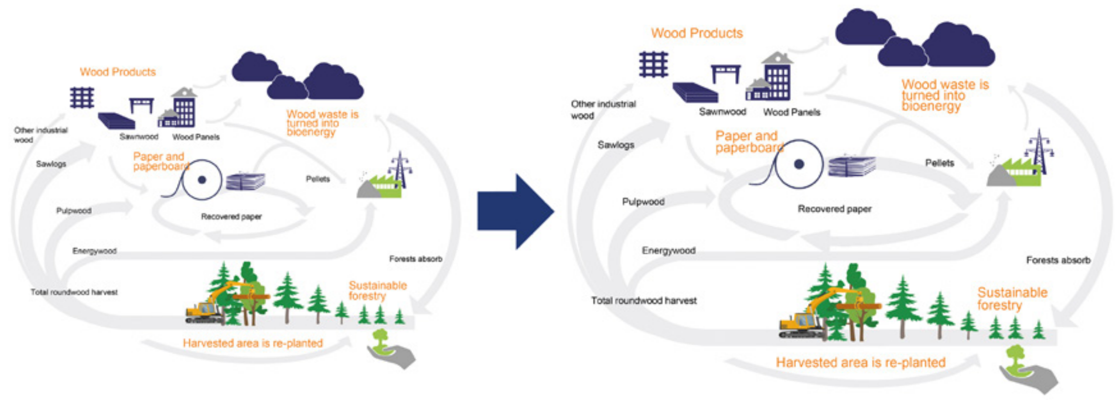
Since we get additional CO_2 storage from the recycling loop, further increasing it also increases storage.

The means that, in order to increase the ‘CO_2 doughnut’ of the recycling loop, we need to:

- increase the recycling rate
- reduce process losses
- keep fibre functional during more than 7 loops (e.g., as a result of new raw materials, such as grasses)
- develop breakthrough technologies in processes and recycling

As the increase in ‘doughnut’ size is a function of all these items, there is no generic rule of thumb for how much an increase in one factor will impact virtual CO_2 storage. However, starting from an 85% recycling rate, 13% losses and 7 loops, Figure 14 gives an indication.

FIGURE 13 | **Growing the CO_2 in the loop**



Recycling rate	*Increasing from 85% to 90%*	*Virtual CO_2 goes from 3.37 ton/ton recovered paper to 3.78 ton/ton*
Process losses	*Decreasing from 13% to 10%*	*Virtual CO_2 goes from 3.37 ton/ton recovered paper to 3.60 ton/ton*
Loops	*From 7 to 8 loops*	*Virtual CO_2 goes from 3.37 ton/ton recovered paper to 3.50 ton/ton*

FIGURE 14 | **Towards rules of thumb for increasing CO_2 storage in the recycling loop**

7.5 Conclusion

As part of the roadmap, we consider the role of recycling.

Recycling turns out to have a significant role in CO_2 storage. A steady, intense loop of recycling paper means a constant, significant amount of carbon (and hence CO_2 equivalent) stored in the loop.

One ton of recovered paper has, given a certain recycling rate, process losses and the number of times the fibre can potentially be recycled, a virtual CO_2 content that is much larger than its content at any given time. This is because a substantial proportion of the very same ton of paper is recycled and used again, many times.

With the current recycling rate of about 85% and assumed losses and loops, about 3.4 tons of CO_2 is bound in one ton of recovered paper. By increasing the recycling rate, decreasing process losses and increasing the time the fibre spends in the loop, we can increase CO_2 storage. This increase is an ongoing process. Since 1990, the virtual content of CO_2 in recovered paper per ton has almost doubled, and even more can be achieved.

8 Outcome

How much does the CO_2 journey cost?

8.1 Abatement costs

The targets of reducing fossil CO_2 by 49% in 2030 and by 95% in 2050 compared to 1990 are challenging, to say the least. If they are to be achieved, a lot of effort will need to be put in, from autonomous development to varying levels of extraordinary effort, up to radical innovation.

8.1.1 Abatement matrix

We have split the CO_2 cake into slices that need to be eaten. Nothing is free and easy, but using different tracks (strategic means) and varying levels of effort (wedges), we have split the scenario into the matrix in Figure 15 (matching the Dutch-language companion flyer). Each cell in the matrix has an associated estimated cost, based on relevant case studies, development curves for technology and rules of thumb.

What do the numbers mean?

Let us take one cell: the medium wedge for sustainable solar energy. This requires extra effort to install solar energy capacity, but no technology breakthroughs or extraordinary efforts to find space for solar panels are required.

The number is the net present value of the total investment (capital expenditure, CAPEX) needed to reduce one ton of CO_2 from the emissions over the whole period of time to 2050. In other words, we have the full cake (from 1990), which is about 1.2 Mt of CO_2. To eat away one ton of it over the whole period to 2050, we will need a CAPEX of EUR 1,800 per ton of CO_2 when using the baseline for solar.

N.B. This is not to be confused with the lifetime cost of reduction. The end result is the same, but then we would calculate the total amount of CO_2 reduced over the whole period and relate that to the investment.

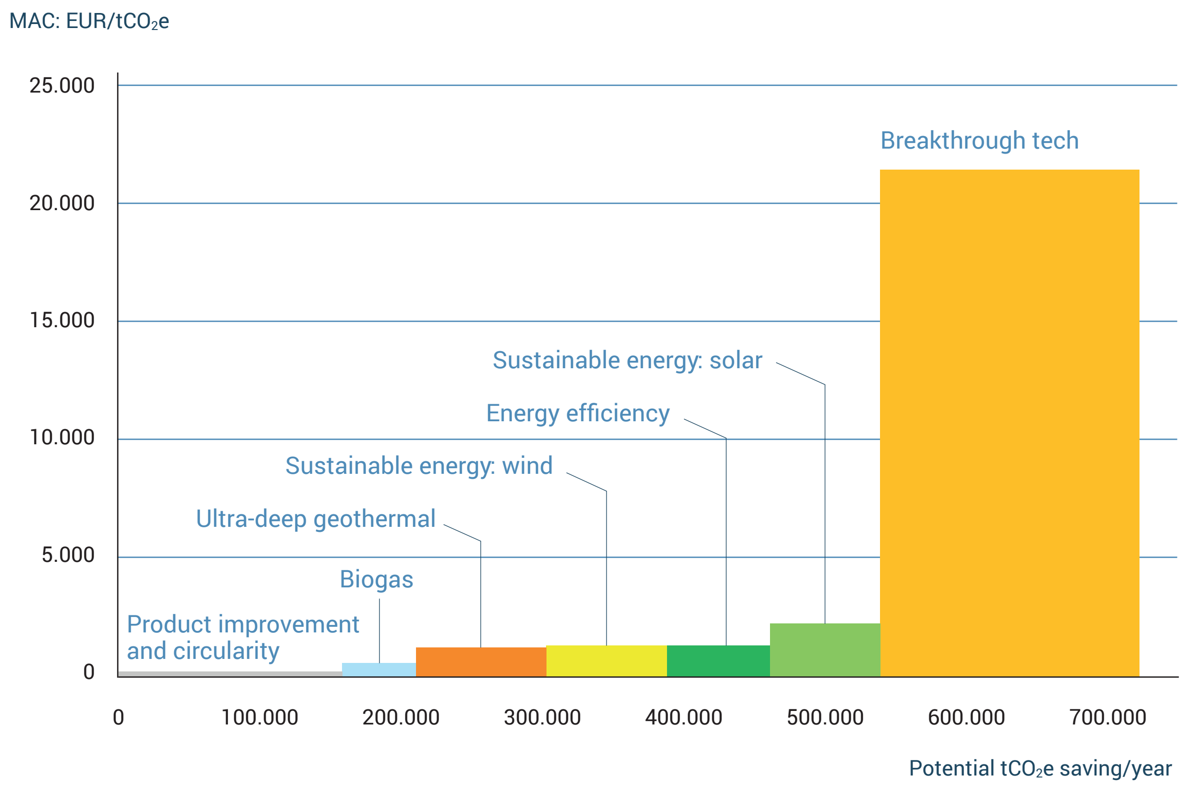
The values calculated exclude subsidies (SDE+ investment in the installation of new productions or refurbishment of the industry).

	Autonomous development	Biogas	Sustainable energy: solar	Sustainable energy: wind	Energy efficiency	Product improvement and circularity	New local fibre raw materials	Geothermal	Breakthrough technologies	Total investments (4,5 billion euro)
RADICAL INNOVATION		600	2.800	1.500	1.500	150		1.100	22.500	3,1 billion euro
HIGH RISK		500	2.300	1.300	1.300	120		900	18.800	1,2 billion
MEDIUM RISK		400	1.800	1.000	1.000	100		700	15.000	0,2 billion
LOW HANGING FRUIT										

Euro per ton CO_2

FIGURE 15 | **Abatement matrix: cost, wedge, track**

FIGURE 16 | **Abatement cost curve**



8.1.2 Abatement cost curve

The matrix can also be shaped as an abatement cost curve, using the amount reduced per year (2050 target levels) and the cost (Figure 16).

8.2 Total costs

An extensive joint investment programme on the part of the industry, the energy sector and the government is required to make the successful transition to a low-carbon, bio-based and circular economy. This stretches from the realisation of a regional infrastructure for a stable sustainable energy supply to the development of breakthrough technologies to make far-reaching reductions in CO_2 emissions possible. It covers the entire process, from idea through pilot to commercial availability, and ultimately application in the paper sector.

To achieve a reduction of 95% by 2050 (excluding electrification and value chain efficiency), an investment of EUR 4.5 billion will be needed, where autonomous development is assumed to entail no additional investment. This means that an additional EUR 4.5 billion is required (EUR 140 million per year) to achieve a CO_2 reduction of 95% by 2050, in addition to the regular investments. On average, this is EUR 6,140 per ton of annual CO_2 emissions. For each ton produced annually (assuming that production stays at the same general level), this means an investment of about EUR 50.

Radical solutions are crucial for the long term. Complex development processes will only be successful if the costs are shared. Cross-sectoral development programmes, such as for industrial heat pumps, ultra-deep geothermal energy or electrification technologies, for instance, will need to be facilitated by the government.

A renewable energy system and the related infrastructure must also be realised in time to enable sustainable electrification of the sector. Investments in this renewable energy system and investments in chain measures were not included in the investment of EUR 4.5 billion mentioned above. This is, on the one hand, because current allocation methodologies (calculation rules) do not provide for this and, on the other hand, because this is beyond the direct sphere of influence of the paper sector. However, it needs to be emphasised that, together, they double the CO_2 reduction speed and potential of our sector.

8.3 Reduction and cost by track

Figure 17 shows an estimate of the cost per ton of avoided CO_2 for each track, calculated on the basis of the net present value, divided by tons of CO_2 over the period up to 2050, and divided by type of measure.

8.4 Reduction and cost by wedge

Dividing the costs by wedge, a significant rise is seen when going from medium via high to radical innovation. Radical innovation represents about 70% of the whole. There is no free lunch, and there is no free cake, either. Eating the CO_2 down to 5% of its 1990 levels demands extraordinary combined effects.

FIGURE 17 | **Total investments by track**

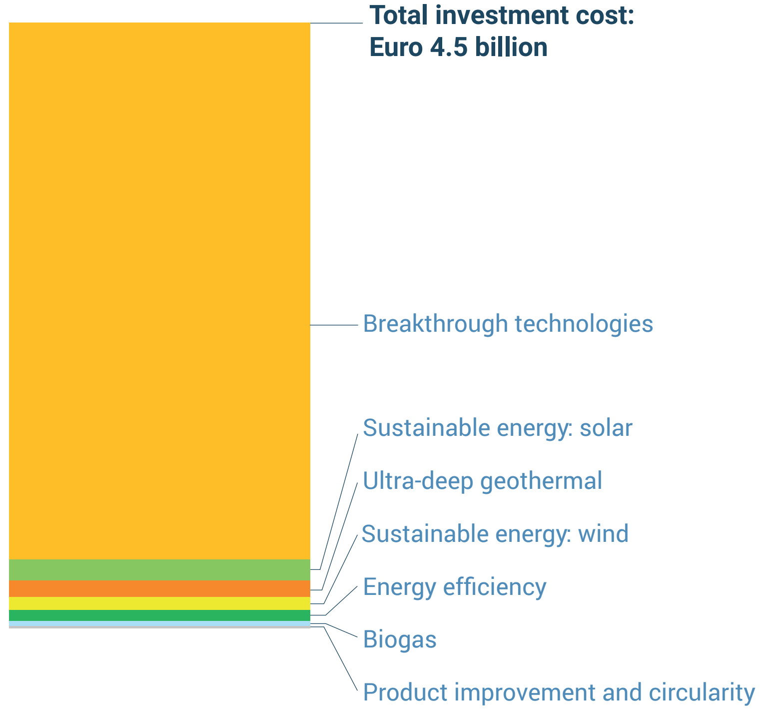
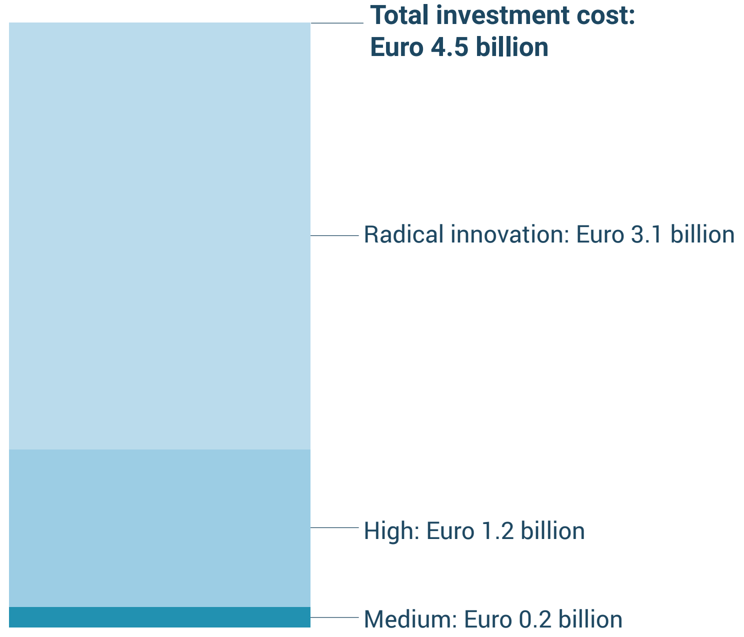


FIGURE 18 | **Total investments by wedge**



8.5 Conclusion

A roadmap targeting the ambitious goals of reducing CO_2 by 49% and 95% respectively, using currently available and reasonably conceivable means, is expensive.

For the roadmap in this report, eating the cake of CO_2 emissions leads to costs of about EUR 4.5 billion in capital expenditure (net present value up to 2050). Sharing the cake will avoid duplication of capital expenditure.

The highest costs are incurred in radical innovation with breakthrough technologies. This makes sense. But *unfortunately*, we cannot take the cheapest means and cut all emissions: the total amount is too large to be achieved using a single means of reduction. *Fortunately*, with the right strategy and support, breakthrough innovations will continue to deliver sustainable success and employment to a green industry.

9 Conclusion

9.1 Need to accomplish an extremely difficult task

Without ambitious targets, it is unlikely that remarkable goals will be reached. However, the task of reducing CO_2 emissions, first by 49% by 2030 and then by 95% by 2050, is extremely demanding.

This does not mean that it is impossible, but there are many conditions and actions that need to be agreed upon.

With an estimated total investment of EUR 4.5 billion, it will also not be feasible without other significant measures. The competitiveness of the Dutch mills has to be maintained, or they will lose in tough international competition and be closed down, with production taking place elsewhere.

Hence, we need to define the actions and conditions that will enable the Dutch paper industry to achieve these ambitious targets.

9.2 Need to act now, define actions and conditions

As the 'metro roadmap' timetable (Figure 5) shows, getting to the 2050 end station successfully will not be possible without a clear plan and early action. Fortunately, the paper industry has already developed a mindset and practice for working on these issues, but there is no time to waste. Likewise, setting the targets for 2030 and 2050 is not enough. The terminal will only be reached if the intermediate stations on the map are reached at the right time. This requires national action now, and a clear strategy and investment in keeping a sustainable industry competitive and alive.

Whatever routes are chosen, the companies will need to be fully supported by dedicated and knowledgeable experts, through collaboration with governments and other sectors, with research and technological breakthroughs, and by investments and the right infrastructure, all in a stimulating financial and legal landscape. This will include the unambiguous and transparent monitoring of all resulting CO_2 emission reductions.

These significant demands, necessary for the successful realisation of governmental targets, are listed below as key actions and conditions.

Investments and infrastructure

- Invest in new concepts and technologies, pilots and demos and their implementation
- Ensure sufficient manpower for research, innovation and implementation
- Increase raw material efficiency, recycling and reuse
- Cooperate with other companies, sectors and the local community
- Increase the capacity of the electricity network and

make it fully CO_2-neutral
- Realise and control a new sustainable energy infrastructure

Fair and unambiguous monitoring and allocation of CO_2 reduction
- Create transparent and stimulating rules for allocation and monitoring
- Stimulate CO_2 mitigation outside the company's premises and beyond national borders through:
  - local raw materials, smart design, lighter products, improved logistics and transport, more reuse and less waste
  - CO_2 storage from the use and recycling of bio-based materials

Ensure fair international competition
- Maintain and strengthen the international competitive position of our companies
- Create a set of instruments for the financial support (OPEX and CAPEX) of unprofitable decarbonisation options

Accelerate R&D and implementation
- Stimulate R&D on innovative technologies
- Cooperate on a large scale in technological innovations that are applicable in several sectors (heat pumps, temporary storage of heat in the soil)
- Accelerate the identification of breakthrough technologies
- Provide subsidies for pilots and demonstration projects

Risk management and guarantees
- Set up a system of risk guarantees to promote investments in high-potential high-risk innovations, such as ultra-deep geothermal energy

Permits and legislation
- Enhance permit procedures for the implementation of innovations
- Include an 'innovation tolerance paragraph' in permits, allowing industries to perform industrial tests using innovative technologies

Increase knowledge and skills
- Develop education and training curricula to train people in the new skills and competences required for the climate revolution

9.3 Final words
Let us conclude by looping back to the beginning. Recycling ideas inside a report makes sense if the content of the ideas binds actions together.

An inspirational roadmap should be backed by the whole sector and lead the transformation of the paper industry. All stakeholders should be fully aware of the importance of the actions involved, and convinced of the routes to be taken.

Is this roadmap 2050 a good story with a happy ending? It is a very intense story of sacrifice and effort over decades. It is a story of very ambitious goals and the need to act early and continuously. A clear threat exists, in that the paper industry is in global competition. For one country to act alone in a significantly uneven competitive playing field implies a great risk of closures and exits. A cost difference of EUR 50/t per paper product is not sustainable and cannot be borne by the industry alone.

However, with the right incentives and support strategy, and by collaborating at the very least across Europe, the synchronised creation of breakthrough technologies and an even more sustainable industry is possible. There is indeed a future, but success is not self-evident.

With a Dutch paper industry that has been flourishing since the 17th century, 2050 would, of course, only be a milestone marking a new beginning, and not the end of anything – except CO_2 emissions.

Annex 1 The paper industry storyline

The storyline of the Dutch paper industry is a combination of 'Rags to Riches' and 'The Odyssey'.

• The Dutch paper industry all started with rags. The next 'rags' could be a mix of new fibres, such as grass and Miscanthus, and new technologies for waterless processes. 'Riches' are a part of a thriving, sustainable industry.

• 'The Odyssey': When historians look back on the Dutch paper industry's successful effort to reach its ambitious emission targets, they will probably not see the story of a clear roadmap followed closely. There will inevitably be a journey with detours, moments of doubt and surprises along the way. However, we have already seen the birth of players such as Amazon, which contributed to changing the paper industry's emphasis by increasing the importance of sustainable packaging. Others will come along, equally surprising and most probably beneficial to sustainable, renewable industries.

There are a limited number of stories in the world: most theories of 'basic storylines' identify only six or seven fundamental plots.

- *'Rags to riches' (The story gets better over time)*
- *'Man in a hole' (Fortunes fall, but the protagonist bounces back)*
- *'Cinderella' (An initial rise in good fortune is followed by a setback, but a happy ending)*
- *'Tragedy' or 'riches to rags' (Things only get worse)*
- *'Oedipus' (Bad luck, followed by a promise, ending in a final fall)*
- *'Icarus' (Starts with good fortune, but doomed to fail)*
- *'The Odyssey' (The protagonist goes to a foreign country and, after overcoming the threats this poses, returns with relevant experience)*

Annex 2 List of figures

This roadmap has been made by a team of Pöyry in close cooperation with VNP and supported by TKI Energie & Industrie.

Photography: Shutterstock / Getty Images / iStock

Design: Studio DAM, Amsterdam

Print: SpringerUit, Schoorl

Contact: Dr. Petri Vasara
Pöyry Management Consulting Oy

P.O.Box 4 (Jaakonkatu 3)
FI-01621 Vantaa
Finland
Domicile Vantaa, Finland
Business ID. FI23022763
Tel. +358 40 500 9553
www.poyry.com

FSC
www.fsc.org
MIX
Papier van verantwoorde herkomst
FSC® C017135