



THE STAFFORD DIARIES | ISSUE #40

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REPOWERING

The investment case for renewing renewables

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EXECUTIVE SUMMARY

Since its inception in 2000, Stafford Capital Partners has aimed to make a difference to the institutional investors that it serves by unlocking complex opportunities in pioneering alternative investment markets. Stafford is highly committed to these specialist markets, creating investment products which can have the potential to offer attractive risk-adjusted returns from stable, operating assets with low carbon-intensity and positive sustainability characteristics. Examples from Stafford's investment activities include its timberland strategies with their carbon-negative profile and its net-zero-aligned infrastructure secondaries strategies.

In this context, Stafford is enthusiastic about the gaining momentum and scaling-up of repowering in the renewable energy sector, particularly for European assets.¹ Stafford believes that as an investment opportunity, repowering shows “secondary market characteristics” similar to those that investors appreciate in its other strategies.

Today's global renewable energy capacity, estimated to exceed 4.400 GW, first started to scale in Europe in the early 2000s before China and the USA took the lead (in terms of size).² Various long-lasting feed-in tariff regimes still in force today supported this growth while climate change and energy security concerns remained active drivers for the continued build-out of Europe's renewable energy capacity, reaching 47% of the EU's electricity generation in 2024.³

However, this rise in European renewables over the last 20 years also implies that there are approximately 150 GW of existing wind and solar assets older than 10 years. These assets are located at top-sites in Europe with outstanding natural capacity however, operating on partially degraded or outdated technology. Through our analysis, we expect these assets to have repowering potential.⁴

From an investor's perspective, Stafford expects most of the private capital to continue to flow into new, greenfield renewable energy projects, while concerns about compressed risk-adjusted returns, complex and long approval processes, increased power price volatility, and carbon- and land-use footprint issues are likely to further rise.

As a result, Stafford believes that revamping and repowering offer a unique opportunity, particularly in Europe, due to:

- the continued growth in European renewable energy,
- the increasing challenges in further greenfield renewable energy developments,
- the aging of existing renewable energy portfolios,
- the decreasing cost of renewable energy components, (with for instance an over 80% drop in the case of PV panels⁵),
- and the increasing regulatory support for repowering at European level.

This issue of the Stafford Diaries outlines in greater detail the investment case for repowering that Stafford recognizes.⁶

We see the significant opportunity to work existing renewable energy assets harder, and believe that through revamping and repowering, it's time to renew renewables!

¹ Repowering - IEA

² Renewable Capacity Statistics 2025 – IRENA 2025

³ European Electricity Review 2025 – EMBER 2025

⁴ Stafford's proprietary analysis

⁵ Renewable Power Generation Cost in 2022 - Irena

⁶ All opinions in this whitepaper are those of Stafford Capital Partners Limited unless otherwise specified.



1. REPOWERING

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Before analyzing the market drivers and the investment case for repowering in chapters 2 and 3, a few definitions and differentiations are required. Since the technical and organizational aspects of repowering projects seem already well covered in research and media, this chapter will focus on the key differences between repowering and revamping, and will broadly outline the investment case for repowering.

1.1 Definitions

The term 'repowering' is often used as shorthand for 'revamping & repowering'. However, while revamping and repowering are both measures to optimize the capacity and efficiency within the boundaries of an existing brownfield renewable energy plant, they do differ:

REVAMPING

Revamping involves replacing components with lower than their original performance, due to aging or damage of the asset. These plants are no longer performing to their original specifications and/or aren't any longer covered under the manufacturer's warranty. The purpose of revamping is to bring such aging or damaged assets back to the approved capacity and production levels aligned with their initial performance, extend warranties of components, and reduce extraordinary maintenance cost. Revamping usually involves the replacement of defective or obsolete PV technologies with modern, more efficient, and more reliable equipment.

REPOWERING

In contrast, repowering is the process of increasing the capacity of existing renewable energy assets by adding new and more efficient components within the boundaries of an existing site to achieve increased energy production as far as the (upgraded) grid connection and permit allows for.⁷

The figure below summarizes the difference between revamping and repowering of a PV plant.

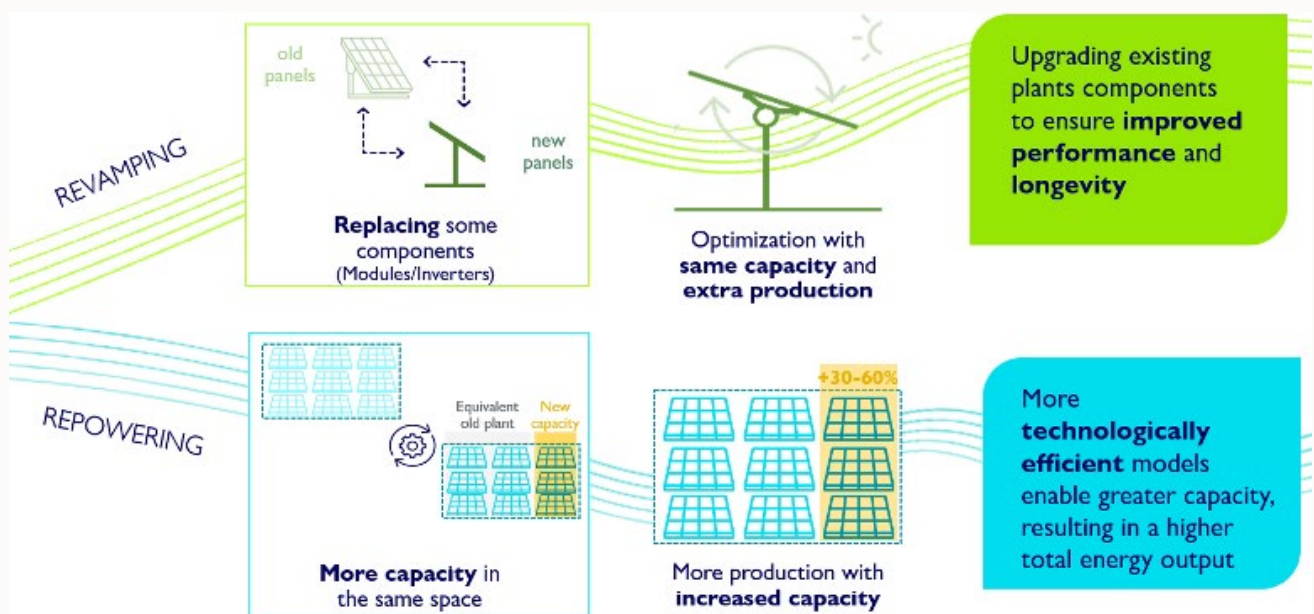


Figure 1: Difference between revamping and repowering in PV energy generation

As will be shown in later chapters, the technological drivers behind revamping and repowering are the significant reductions in their cost/megawatt- and land/megawatt-ratios of renewable energy components achieved over the last couple of years making revamping and repowering particularly attractive at older plants that still benefit from high feed-in-tariffs.⁸

⁷ What is Repowering? - Energy Theory

⁸ Clean Energy Equipment Price Index - IEA

1.2 Revamping versus repowering

The choice between applying revamping or repowering to an existing renewable energy asset depends on several factors and often results in applying both measures in combination.⁹ These factors include:

- **Grid Availability:** the primary determining factor for revamping versus repowering is the grid's availability to off-take more energy production from a plant with a higher capacity. The request for extra capacity from existing, old plants could be more successful than requesting new capacity from new plants. This is because the existing assets have on average, much lower increase requests than utility-scale greenfield projects, plus they are already connected to existing substations. If sufficient grid availability is ensured, repowering typically represents the better option over revamping.¹⁰
- **Economic Considerations:** Even in case of grid availability the choice between repowering and revamping further depends on the economic analysis of required capital for revamping and/or repowering in relation to the expected extra production. The economic analysis needs to factor in all the activities required to achieve the final extra production target.
- **Regulatory Approvals:** The process of obtaining regulatory approvals for repowering projects can be more complex and time-consuming than for revamping, as it often involves significant changes to the existing infrastructure.
- **Environmental Impact:** In the case of wind farms, repowering can often reduce the number of wind turbines on site, leading to less noise and potentially less impact on bird migration, which can be beneficial to the local environment.¹¹

Deciding upon the optimal mix of revamping and repowering measures on any given site and managing any corresponding, on-the-ground implementation of such measures requires significant project management and technical expertise. We believe that analyzing these factors holistically is critical for this type of project to succeed, particularly compared to greenfield projects, which tend to be less complex.

1.3 Holistic optimization of renewable energy assets

As shown, revamping and repowering play a crucial role in maintaining and enhancing the performance of older renewable energy assets. The choice between the two depends on a variety of factors, including the technical condition of the plant, economic considerations, the regulatory and policy context, as well as environmental benefits.

However, both measures represent only one set of optimization actions that an active asset owner would consider. Other common 'renewable energy asset optimization measures' can include:

- a comprehensive asset sourcing & acquisition strategy (including potential discounts),
- operational plant performance improvements (such as advanced cleaning and maintenance routines),
- attractive financing conditions (including bank but also manufacturer financing), and
- a comprehensive exit strategy for an enhanced exit multiple on a portfolio basis.

⁹ [Revamping and repowering renewable energy assets – Vector Renewables](#)

¹⁰ [Repowering vs revamping: what's the difference? - BayWa](#)

¹¹ [Repowering: Definition, History, & Benefits - Carbon Collective](#)

Figure 2 below analyzes the single measures for holistic optimization of renewable energy assets, highlighting their potential contribution of each of them to the final IRR. Although all these measures play a role, repowering/revamping can have a particularly strong impact in the current market environment. The figure is based on indicative targets, reflecting internal portfolio analysis and performance improvement expectations and signals that repowering, by increasing energy production with limited additional capex, tends to lead to a higher increase in IRR compared to other measures.

Repowering within the Suite of Optimization Measures



Figure 2: Illustrative suite of renewable energy asset optimization measures





2. MARKET DRIVERS FOR REPOWERING

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Following the definition of terms in chapter 1, the investment case for repowering starts to build by understanding its market drivers, such as:

- continued growth in European renewable energy,
- increasing challenges in further renewables energy development,
- aging of existing renewable energy portfolios,
- decreasing cost of renewable energy components, and
- increasing regulatory support for repowering at European level.

2.1 Continued growth in European renewable energy

As fund secondary markets in infrastructure or private equity often depend on their respective underlying primary markets, repowering opportunities are generally a function of the installed capacity of renewable energy generation assets in any given vintage year. To understand the repowering opportunity, a look at the historic and future growth patterns of the installed renewable energy capacity is essential.

Focusing on Europe, renewable energy build-up, at scale, started in the late 1990s supported by various incentive schemes provided by individual states.¹² This has reached a total installation capacity of 902 GW¹³ today. Approximately 50% of the renewable energy capacity installed in Europe has benefited from these state incentives, the effects of which remain impactful today.¹⁴ More recently, the energy contribution of renewable energy has grown at pace from a 34% share in 2019 to 47% in 2024. The share of fossil fuels declined from 39% to 29% over the same period.¹⁵

Figure 3 below summarizes the growth of the European installed capacity of renewable energy generation assets since 2000:

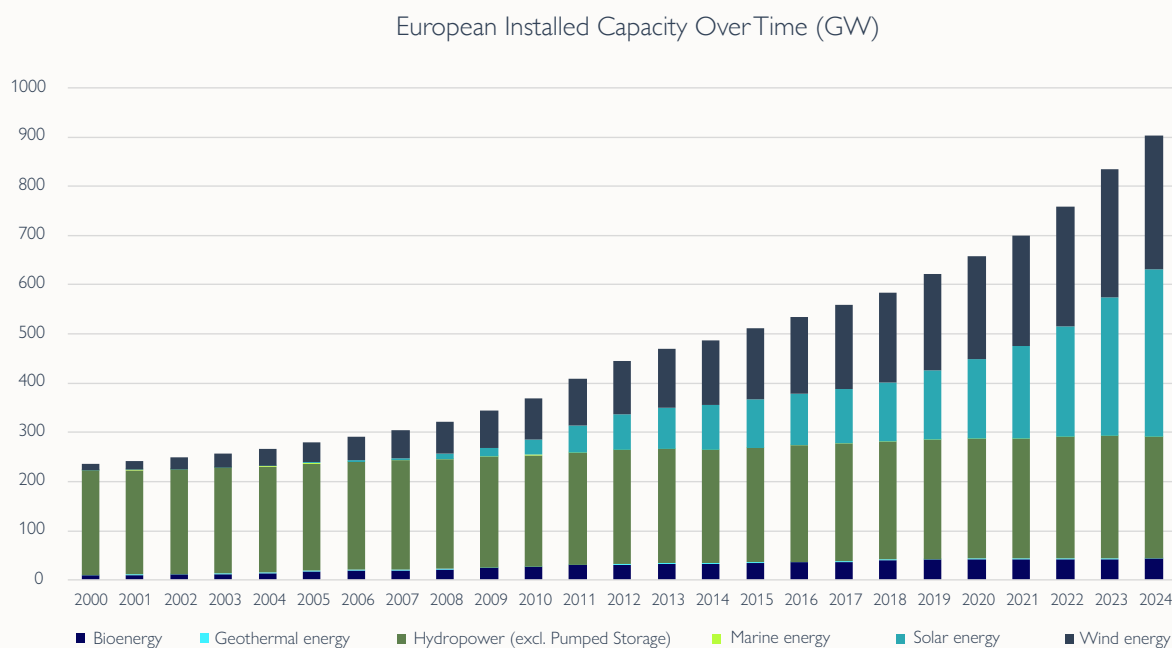


Figure 3: Installed capacity of European renewable energy assets since 2000¹⁶

¹² [A History of Renewables Energy - EIB](#)

¹³ [Renewable capacity statistics 2025 – IRENA 2025](#)

¹⁴ [Status Review of Renewable Support Schemes in Europe for 2020 and 2021 - CEER](#)

¹⁵ [European Electricity Review 2025 – EMBER 2025](#)

¹⁶ [Statistics Time Series - IRENA 2025](#)

From here, the build-up of renewable energy assets in Europe (including the United Kingdom) is expected to continue. This is recognised in consideration of decarbonization efforts and energy security planning, acknowledging that the EU does not have sufficient supplies of fossil fuels¹⁷ to support energy capacity needs.

Regarding decarbonization objectives, the energy sector is responsible for more than 75% of the EU's greenhouse gas emissions.¹⁸ Therefore, increasing the share of renewable energy across the different sectors of the economy is a key building block for reaching the goal of reducing net greenhouse gas emissions. Goals set by the EU include reducing net GHG emissions by at least 55% by 2030 and becoming a climate-neutral continent by 2050. It is also key for the EU to meet the targets set within the Renewable Energy Directive (RED III) by 2030, including achieving at least a 42.5% share of renewable energy in gross final energy consumption by 2030¹⁹ (this is in comparison to the current share of 24.5% in 2023²⁰ in the overall energy mix (including electricity, heating and cooling, and transport)).

Renewable energy will not only help “the EU transition towards a prosperous, sustainable, climate-compatible and independent economy”²¹, but in addition is expected to make the European energy system more affordable and reduce the EU's dependency on imported fossil fuels.

Regarding energy security, a renewable-based energy system offers the possibility of a resilient, secure and affordable system that is considered in alignment with the development of interconnected infrastructure.²²

2.2 Current challenges in European renewable energy

Alongside the continued build-out of renewable energy capacity in Europe, as described in [Chapter 2.1](#), and the implied need for upgraded grid infrastructure, several challenges have emerged with respect to meeting the objectives set out by the EU in its energy security planning. This has been particularly in relation to developing new greenfield renewable energy sites, therefore further enhancing the case for the repowering of existing brownfield assets:

- **Grid Access:** One of the primary bottlenecks in the deployment of new renewable energy projects across Europe is the limited availability of grid connections. Existing transmission and distribution networks are often insufficient to accommodate the new decentralized and intermittent energy flows, resulting in connection delays, curtailment risks and underutilized capacity.²³
- **Storage:** To increase the ‘base load’-capabilities of renewable energy (i.e., ensuring a constant energy supply) and to optimize sale prices of the energy produced in an increasingly merchant power market, significantly more (battery) storage is required. While advancements in power generation technologies have been made, further research and development related to storage and distribution is required to better adapt the new energy system and infrastructure.²⁴
- **Land and Resource Availability:** Renewable energy projects often require large amounts of land compared to traditional energy sources. This can lead to conflicts over land-use and resource allocation, particularly given dense European population patterns. Figure 4 below shows examples of the high concentration of wind power plants in the best European wind areas (with red shades indicating most favorable locations).²⁵
- **Political Barriers:** The transition to renewable energy often faces political barriers. These include permitting idle and frequent regulatory changes with high granularity multiplied by lack of harmonization across (EU) countries.²⁶
- **Awareness and Acceptance:** The significant increase of installed renewable energy capacity is clearly changing the landscape and the countries' stock of natural capacity. As a result, people's awareness of and attention to the land-use intensity of new greenfield developments has increased while acceptance of such greenfield projects has reduced. In Italy, for example, new ground-mounted photovoltaic plants obtain higher acceptance by the local communities and therefore often benefit from a quicker and smoother permitting process if they are installed in a way that allows farming beneath them (i.e., ‘agrivoltaics’).²⁷ Projects without comprehensive land-use considerations face increasing risks of permitting delays or even failures.

17 [Energy security in the EU – Energy Transition Commission](#)

18 [Renewable energy targets – European Commission](#)

19 [Renewable Energy Directive – European Commission](#)

20 [Renewable energy statistics - Eurostat](#)

21 [Renewable energy - European Environment Agency](#)

22 [Reimagining European energy security](#)

23 [Europe's grids become green power growth bottleneck – Reuters](#)

24 [The Energy Transition – The Oxford Institute for Energy Studies](#)

25 [Vortex database map - Vortex](#)

26 [Speeding up renewable energy permitting in Europe - Centre on Regulation in Europe](#)

27 [Agrivoltaics in Italy and efficient land-use - ENEL](#)

Stafford believes that repowering can address these challenges well as repowering measures focus on existing fully permitted plants with operating grid connections.

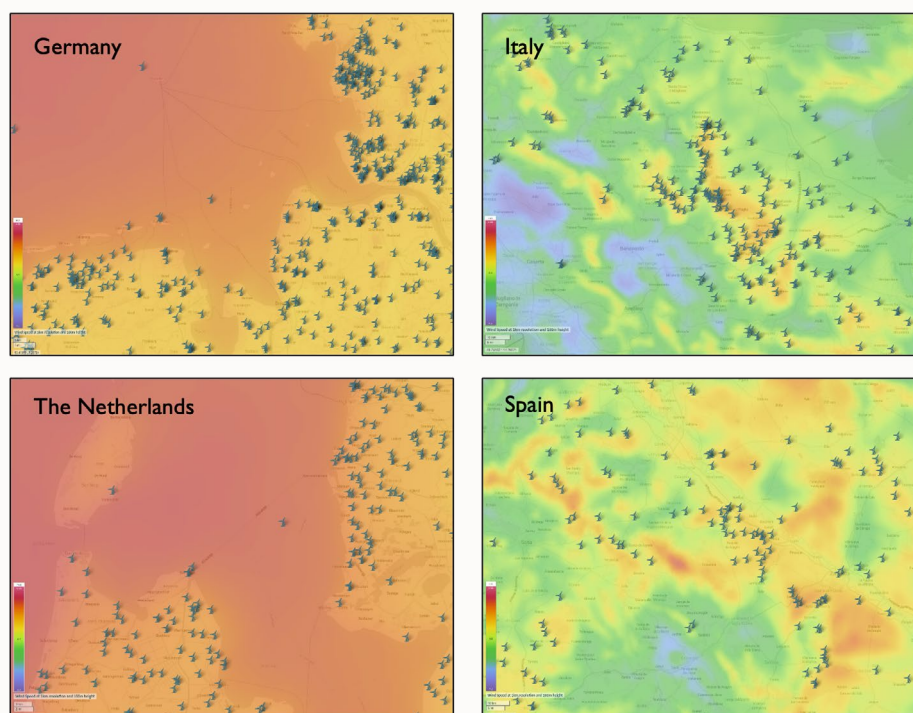


Figure 4: Examples of density among European wind assets

2.3 Growing portfolio of aging renewable energy assets

The key market driver for increased repowering opportunities remains at large due to the growing number of renewable energy generation assets older than 10 years, but which are still operating under an attractive feed-in tariff regime for a further 5 to 10 years.^{28, 29, 30} The production capacity of renewable energy generation assets degrades approximately 0.5% per year. This is so that the gap between current performance and original capacity for which the feed-in tariff was granted, usually becomes material after 8 to 10 years in operation.³¹

Stafford's proprietary research suggests that there are currently 150 GW of installed capacity assets with repowering opportunity in Europe, with ca. 80 GW occurring in photovoltaics and ca. 70 GW in wind.

Moreover, Stafford considers that this cumulative amount is likely to be just the beginning of the growing repowering market in Europe. As Europe has continued to add capacity year on year, the fleet of 10-year-old renewable energy assets will grow correspondingly. In fact, Stafford's internal research suggests that over the next 4 years, an additional 62 GW of capacity, built between 2015 and 2018, might be added to the 150 GW of repowering potential already available today. This suggests there may be an interesting concentration of opportunities over the next few years.

In addition, the repowering opportunities in markets outside of Europe will add additional volume as the fleets of solar and wind assets in these markets mature; Stafford continues to track these regional developments.

²⁸ [Renewable Energy Generation: Incentives Matter](#)

²⁹ [Understanding the ROC transfer payment](#)

³⁰ [Feed-in Premium Programme SDE + - IEA](#)

³¹ [Wind Turbine Performance Decline with Age](#)

Figure 5 shows the expected repowering potential in Europe over the next few years, based on 70% of the installed capacity 10 years earlier. For the next 4 years this projection suggests an additional repowering potential of around 62 GW in addition to the 150 GW repowering potential already existing today (as mentioned above). This trend mirrors the growth path seen in greenfield installations between 2015 and 2018, providing investors with high visibility over potential future project pipelines. Stafford expects the cumulative growth curve for repowering to follow a stable trajectory, closely aligned with the expansion of renewables over the past 10-15 years.

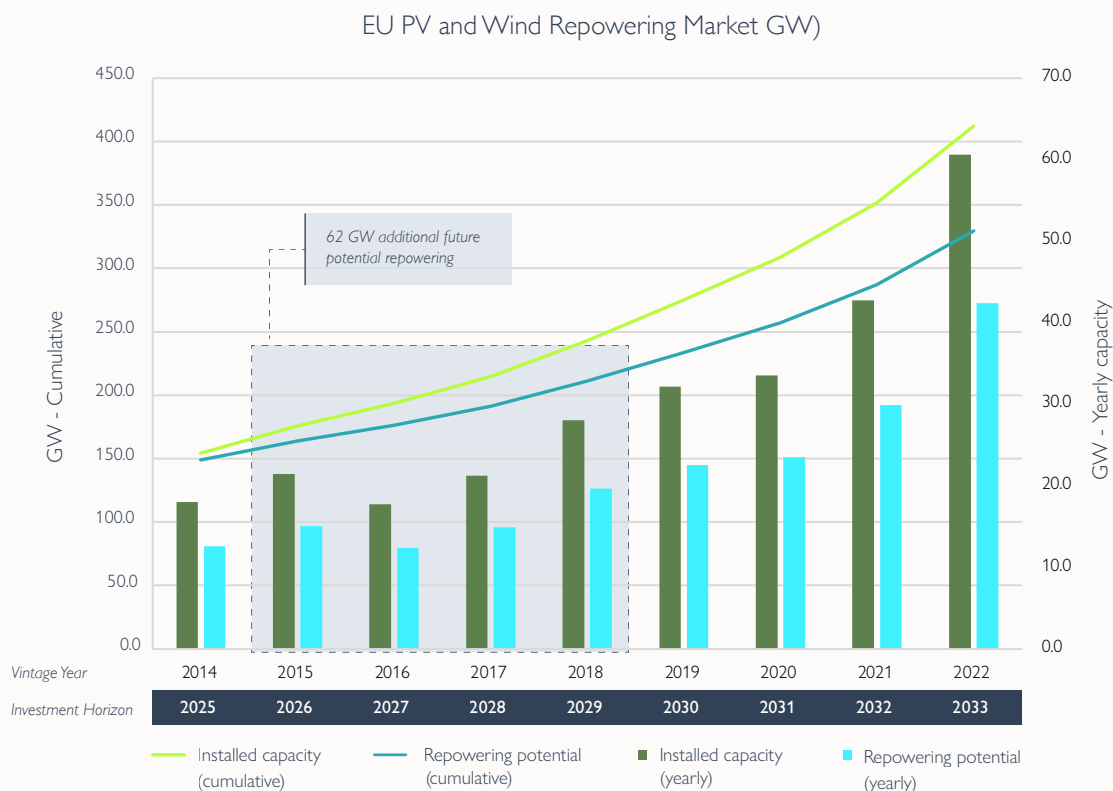


Figure 5: Repowering potential in Europe 2025-2028³²

³² Stafford proprietary analysis



2.3.1 Repowering potential in European PV assets

Between 2008 and 2014 (i.e., the target vintages for repowering today), Europe experienced a rapid expansion in renewable energy capacity, particularly in photovoltaics and wind as referenced before. This period marked the beginning of a transformative shift in the energy landscape, driven by policy support, technological innovations, and a collective commitment to sustainability. These installations typically still benefit today from both generous subsidy schemes and prime locations, potentially making any improvement to production particularly beneficial. The opportunity is, however, not uniform throughout Europe: volumes built over time, legislation and potential for increased capacity all vary by jurisdiction.

GERMANY

In 2008, Germany emerged as the leader in solar capacity, with an installed base of approximately 6 GW. This rose to approximately 38 GW by 2014. The remarkable growth in Germany was driven by generous feed-in tariffs and robust governmental support mechanisms, making Germany a global case study of solar energy adoption.³³

ITALY

Italy, initially lagging with only approximately 1 GW of installed PV capacity in 2008, experienced a rapid expansion, reaching approximately 19 GW by 2014. The introduction of the “Conto Energia” scheme, which offered among the highest feed-in tariffs for solar energy in Europe, attracted significant investment and accelerated the deployment of photovoltaic systems across the country.³⁴

IBERIA

Iberia also played a key role, with its solar capacity increasing from approximately 3 GW in 2008 to approximately 5 GW in 2014. Although the growth rate was more modest compared to its European counterparts, Spain maintained a prominent position in the solar market despite a retroactive reduction in incentives following the 2008 economic downturn.^{35,36}

FRANCE

France's solar sector, with less than 1 GW in 2008, expanded significantly to ~6 GW by 2014. This growth was driven by regulatory incentives and guaranteed electricity prices, which ensured stable revenue and encouraged PV-development by promoting cost-effective deployment through competitive tenders.³⁷

UNITED KINGDOM

The UK, starting with hardly any PV installations in 2008, experienced exponential growth reaching approximately 6 GW by 2014. This extraordinary increase was driven by a combination of feed-in tariffs for small-scale systems and Renewable Obligation Certificates (ROCs) for larger installations, alongside policy frameworks that promoted renewable energy adoption.³⁸

THE NETHERLANDS

The Netherlands, though relatively small in its initial capacity, saw its solar installations grow from hardly any installations in 2008 to just over 1 GW in 2014. This growth was supported by national subsidies and the Sustainable Energy Transition scheme (SDE+) that supported solar PV by providing feed-in premiums to bridge the gap between market prices and production costs.³⁹

THE NORDICS

Solar PV deployment in the Nordics remained limited between 2008 and 2014, with only modest growth supported by local or national subsidies. Only Denmark introduced feed-in tariffs for small-scale PV in 2010, while Sweden and Finland focused on tax rebates and investment grants rather than production-based support.⁴⁰

33 [The German incentive regulation](#)

34 [Renewable Energy Generation: Incentives Matter](#)

35 [Effectiveness and efficiency of support schemes – Sciences Direct](#)

36 [Portugal, a strong bet on renewables – Universidad da Navarra](#)

37 [France's Government Policies on Sustainable Energy - BillionBricks](#)

38 [Understanding the ROC transfer payment – Science Direct](#)

39 [Feed-in Premium Programme SDE+ - IEA](#)

40 [PV Power Application in Sweden - IEA](#)

EUROPE'S TOTAL INSTALLED CAPACITY IN PHOTOVOLTAICS

Overall, considering all European countries, Europe's total installed capacity in photovoltaics grew between 2008 and 2014 to approximately 82 GW. This represents approximately half of the estimated 150 GW repowering opportunity in Europe. Figure 6 below summarizes the development.

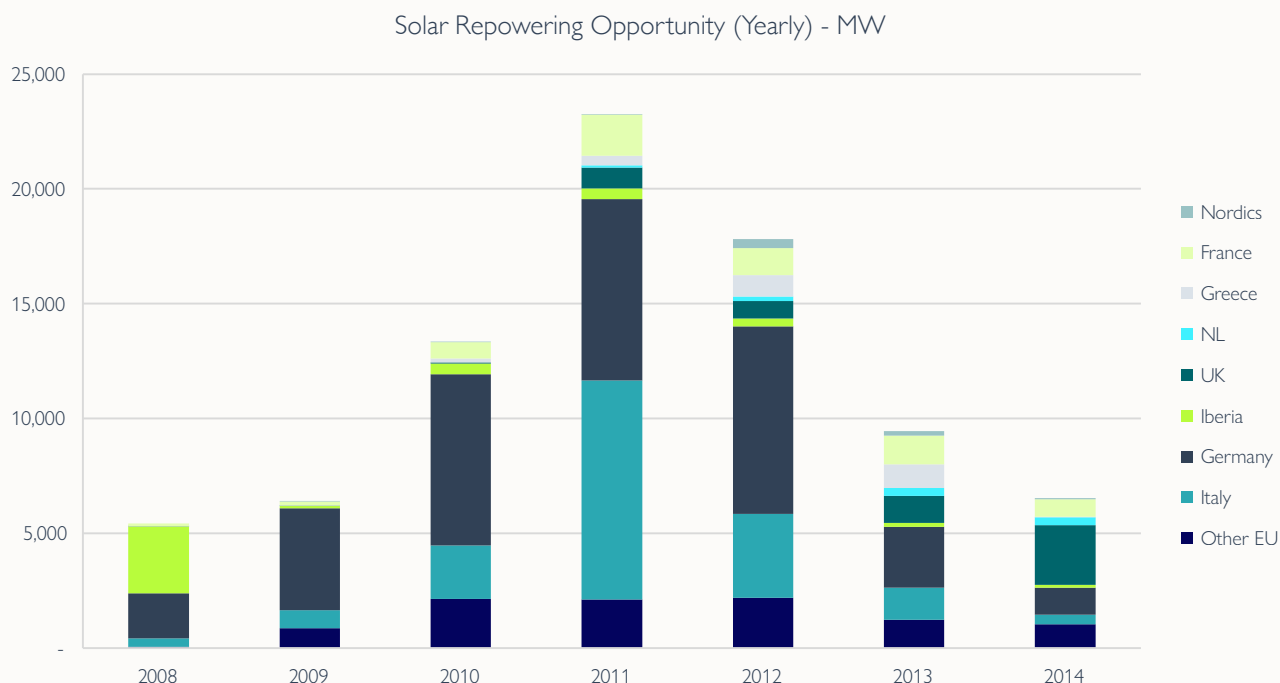


Figure 6: Repowering opportunity in European photovoltaics⁴¹

2.3.2 Repowering potential in European wind assets

Wind power also experienced substantial growth across Europe during the period 2008 and 2014.

GERMANY

Germany again led the way with its installed capacity growing from approximately 24 GW in 2008 to approximately 40 GW by 2014. The expansion was facilitated by continuous support and stable policies that fostered a conducive environment for wind energy development by introducing feed-in tariffs specifically for wind energy and ensuring long-term fixed payments for electricity generated by wind turbines.⁴²

ITALY

Italy's wind power sector also expanded, with installed capacity increasing from approximately 4 GW in 2008 to approximately 9 GW by 2014. This growth was supported by national policies and incentives such as the "Green Certificates" that encouraged the deployment of wind energy by providing additional revenue streams based on the renewable energy produced.⁴³

IBERIA

Iberia, with approximately 20 GW of wind capacity in 2008, increased to approximately 28 GW by 2014. Despite a slower growth rate compared to earlier years, Iberia remained a significant player in the wind energy sector, aided by long-term policy frameworks pre-2008.⁴⁴

⁴¹ Stafford proprietary analysis

⁴² [The impact of a feed-in tariff on wind power – Science Direct](#)

⁴³ [Effectiveness of Incentives for Wind Energy - ResearchGate](#)

⁴⁴ [Iberia - Giants and windmills - ResearchGate](#)

UNITED KINGDOM

The UK saw its wind capacity expanding from approximately 3 GW in 2008 to approximately 12 GW by 2014. This rapid growth was driven by incentives for both onshore and offshore wind projects, making the UK a leading market for wind energy.⁴⁵

FRANCE

France's wind capacity grew from approximately 3 GW in 2008 to approximately 9 GW by 2014, an increase driven by a combination of feed-in tariffs for smaller onshore wind projects and competitive auctions for larger wind farms across the country.⁴⁶

THE NETHERLANDS

The Netherlands increased its capacity from approximately 2 GW in 2008 to approximately 3 GW in 2014, thanks to supportive national policies and incentives. The SDE+-scheme provided subsidies covering the difference between market electricity prices and the higher costs of wind energy production.⁴⁷

THE NORDICS

The Nordics have a long-standing tradition of wind energy development and between 2008 and 2014, the region increased its total installed wind capacity from 0.4 GW to over 7.3 GW, marking a rapid and steady expansion. Denmark, in particular, relied on stable feed-in tariffs and premium tariffs, while Sweden and Norway introduced a joint green certificate system from 2012.⁴⁸

EUROPE'S TOTAL INSTALLED CAPACITY IN WIND

Other European countries collectively grew their wind capacity, reaching a cumulative European capacity of approximately 72 GW installed between 2008 and 2014 and available now for repowering. Figure 7 below summarizes the development.

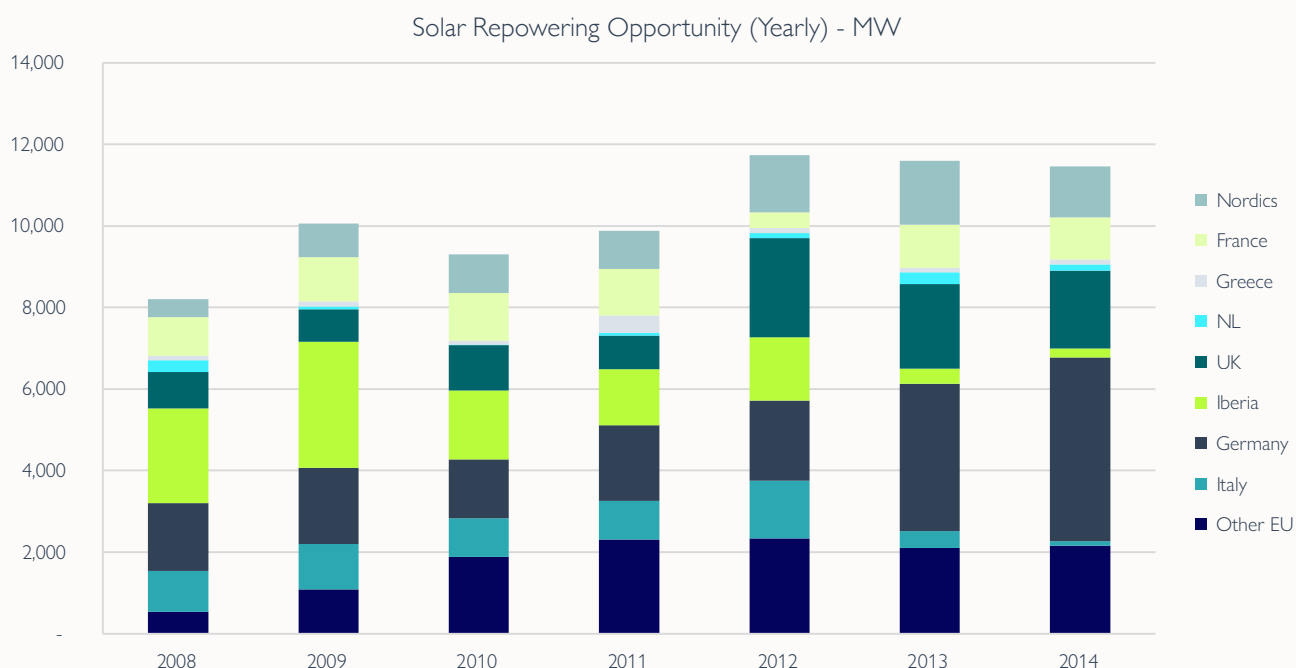


Figure 7: Repowering opportunity in European wind power⁴⁹

⁴⁵ [Wind energy in the United Kingdom – Science Direct](#)

⁴⁶ [Wind energy tariffs – Clifford Chance](#)

⁴⁷ [Feed-in Premium Programme SDE+ - IEA](#)

⁴⁸ [Promotion of Renewable Energy - IEA](#)

⁴⁹ Stafford proprietary analysis

2.4 Decreasing cost of more efficient equipment

As shown above, the repowering opportunity in Europe is emerging. Stafford believes it is set to further grow given new vintage years becoming available for repowering and with fleets of solar and wind assets maturing in regions outside of Europe. However, besides the size of the fleet to be repowered and the attractiveness of the 'feed-in tariff tails' associated with them, there is an additional important market driver for repowering: *cost depreciation*.

Compared to 10 years ago there has been a significant reduction in the cost of renewable energy components. By replacing outdated components, such as turbines or panels, with new pieces of equipment that are significantly cheaper and more efficient than 10 years ago, repowering allows an increase in capacity as well as higher efficiency within the boundaries of a given site. This can lead to an increase in energy generation, lower carbon-intensity, lower land-use per mega-watt, and overall better performance.⁵⁰

Research shows, for example, that the average capacity-weighted cost of installed photovoltaic projects commissioned in 2023 amounted to approximately USD 750/kW, 86% lower than in 2010. In the same way, the capacity-weighted cost of onshore wind fell 49% between 2010 and 2023, from approximately USD 2'270/kW to USD 1'160/kW. In 2023, prices dropped by approximately 12% on the 2022 value driven by continued cost declines, particularly in China.⁵¹ Figure 8 shows this price decline over time.

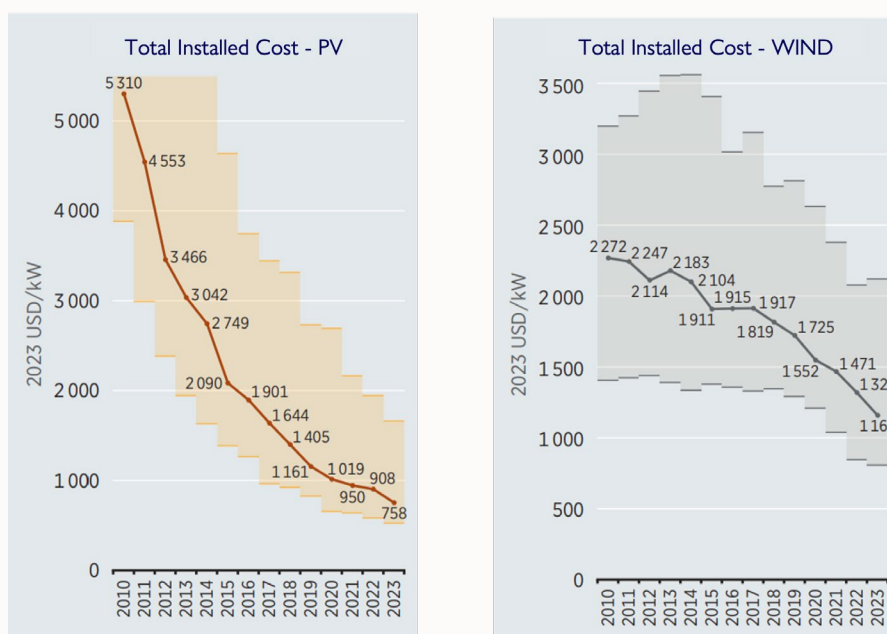


Figure 8: Declining cost of renewable energy projects⁵²

However, not only has the cost of installing a solar or wind project fallen significantly over the last 10 years, but the efficiency of the PV-modules and wind turbines has increased. For example, the efficiency of the typical solar panel has increased by approximately 40%. This has led to more electricity being produced per square meter of used land and thereby reducing the land-use of such plants.

Besides the better technological efficiency of the latest solar panels, further efficiency gains can be achieved in a repowering project by switching from fixed-axis structures to tracking panels (i.e., panels installed on moving structures following the sun).

As a result of such efficiency gains, revamping (i.e., replacing existing capacity only) of fixed-axis structures increases production on average by 12% (approximately), while revamping, including the use of tracker systems, increases production by up to 30%.^{53,54}

⁵⁰ Photovoltaics Report – Fraunhofer ISE

⁵¹ Renewable Power Generation Cost in 2024 - Irena

⁵² Renewable Power Generation Cost in 2024 - Irena

⁵³ Ageing, PV modules degradation – PVsyst.com

⁵⁴ Fixed tilt vs tracker system comparison – PV Case

In the case of solar repowering (i.e., adding additional capacity within the boundaries of an existing plant) and using the existing fixed-axis structures (i.e., using the ‘empty’ spaces on the existing structures that aren’t needed for replicating prior capacity by new, more efficient modules), Stafford assumes that a plant with unchanged land-use could experience a 50% increase in capacity and up to a 70% increase in its production.

Similarly to solar panels, wind turbines have experienced a significant increase in efficiency over the last 10 to 20 years. Figure 9 below shows that the average rotor diameter of a wind turbine has increased by more than 78% from 70m to 125m during the period of 2000 to 2020. Additionally, the hub height has also significantly increased from 80m to approximately 135m, reflecting a +69% growth.⁵⁵

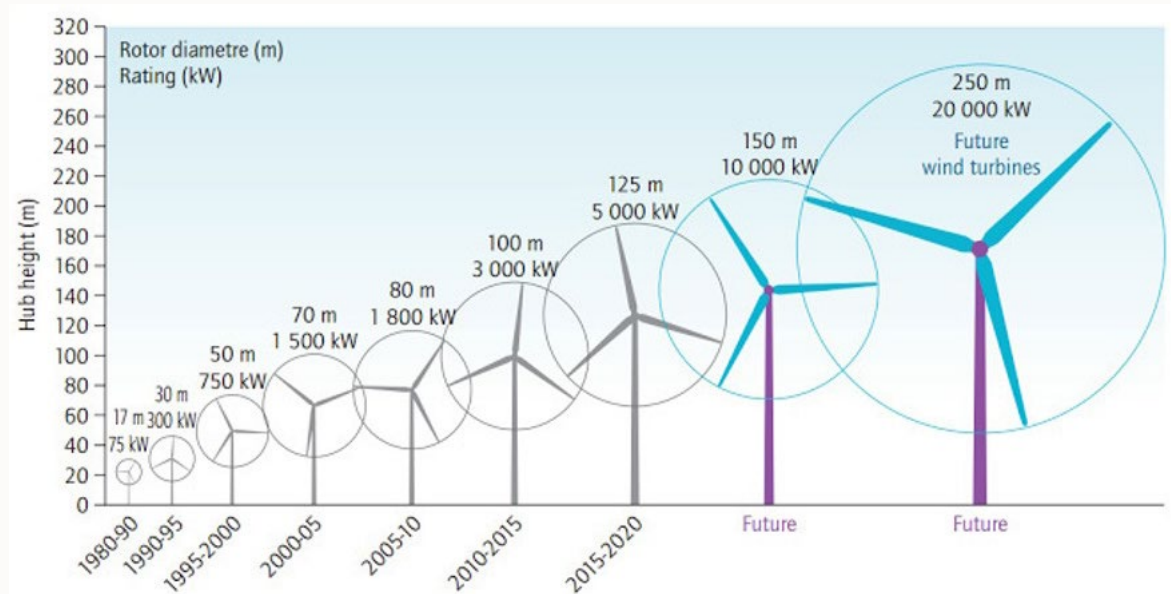


Figure 9: Efficiency gains of wind turbines over time⁵⁶

These technological advancements in the construction of wind turbines have resulted in an increase of the rated capacity of a turbine from ~1.5 MW in 2000 to approximately 5 MW today. This represents more than 3x in terms of installed capacity, directly resulting in higher production levels.

In essence, repowering benefits the efficiency and performance of the sites. By replacing outdated components with newer technology this can lead to increased energy capacity and boost efficiency, whilst upgrading turbines or panels can capture more energy from the same resources and allows for higher energy output by optimizing performance. Repowered renewable energy plants therefore generate more electricity with lower carbon-intensity (given the re-use of concrete and steel of the existing structures) than before within the same land-footprint.⁵⁷

⁵⁵ [Wind Energy Conversion System – Research Gate](#)

⁵⁶ [Wind Energy Conversion System – Research Gate](#)

⁵⁷ [Solar vs. Wind - VVEF](#)

2.5 Regulatory support for repowering

Increased regulatory support for repowering projects across Europe represents a fifth driver for the emerging institutional repowering market. This is mainly in the form of a simplified permitting process, for which repowering can offer several advantages over new greenfield projects.⁵⁸

Such permitting processes are generally governed by national and regional regulations, which can vary significantly throughout Europe. These regulations typically govern environmental impact assessments, land-use planning, and grid connection approvals, for which repowering projects are at a distinct advantage.

The European Union has recognized the need to speed up the permittance of renewable projects generally but also explicitly for repowering projects too. For instance, the European Union's Renewable Energy Directive (RED) has set maximum deadlines for granting permits of two years for new greenfield plants but only one year for repowering projects.⁵⁹

In addition, Germany, Spain, and Portugal have introduced the concept of "renewable acceleration areas". These are specific locations, particularly suitable for the installation of renewable energy plants, where the deployment of a specific type of renewable energy is not expected to have significant environmental impacts. The permitting process in these areas is expedited, with a maximum deadline of one year for new greenfield projects but only six months for repowering projects.⁶⁰

Moreover, the Italian government has introduced new simplification rules for renewables and has simplified the process for wind and photovoltaic repowering and revamping. New quantitative specifications have been introduced to classify changes as 'non-substantial modifications' for installations and projects already in place. Again, to speed up the process in the case of repowering.⁶¹

58 [EUR-Lex – European Union](#)

59 [Permitting – WindEurope](#)

60 [Revised EU Renewables Directive set to speed up wind permitting – WindEurope](#)

61 [D.L. Energia – Dentons](#)



Given the continued political interest in increasing the power production from renewable sources, Stafford assumes continued favorable regulatory support for repowering across Europe. However, as it is likely that country-specific differences will remain, Stafford has brought together its internal assessment of the various regulatory aspects in a matrix shown in Figure 10 below. Stafford's 'Repowering Market Attractiveness Matrix' compares Stafford's determination of the attractiveness of the revamping/repowering opportunity in selected European countries with large installed wind and solar capacity against:

- a) the size of the opportunity,
- b) the attractiveness of the applicable incentive schemes, and
- c) the implementation complexity linked to the permitting scenario.

In the matrix the 'Feed-In Tariff (FIT) Attractiveness' is quantifiable in Euro amounts while the 'ease of permitting' is not. Therefore, Stafford has created a corresponding 'Permitting Ease Index' comparing the administrative and regulatory requirements for repowering/revamping projects against those of new greenfield developments. Values of the index range from 1 (little difference) to 5 (much greater simplicity) when comparing the approval processes for repowering versus greenfield projects. The bubble size, on the other hand, represents the size of the repowering market in GW (analyzed in the previous chapters).

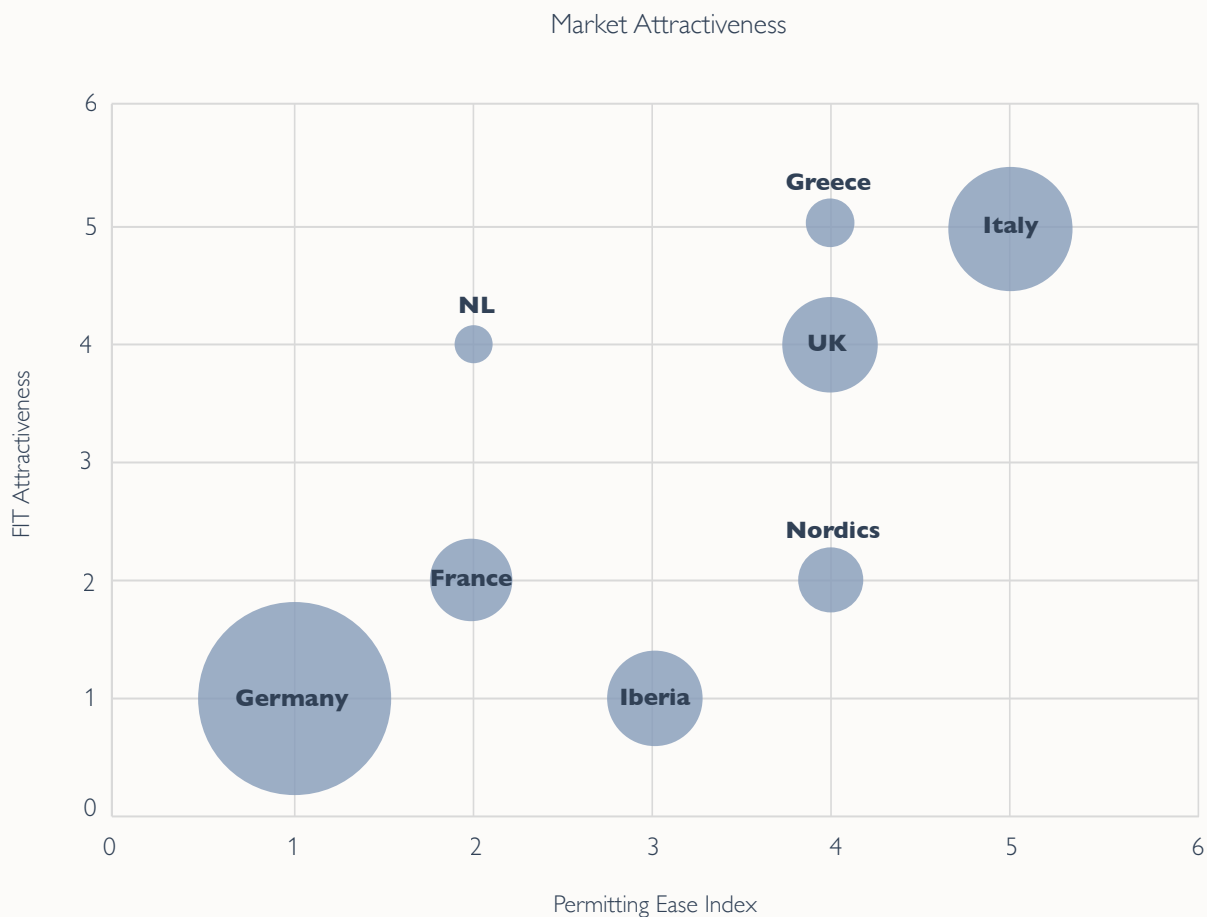


Figure 10: 'Repowering Market Attractiveness Matrix'⁶²

⁶² Stafford proprietary assessment



3. INVESTMENT CASE FOR REPOWERING

3. INVESTMENT CASE FOR REPOWERING

Generally, an institutional investor interested in investing in renewable energy generation assets in established renewable energy markets (such as Germany, Italy, the UK), can invest into:

- **early development projects,**
- **development projects that have received permits and are ready to build (RtB-projects), or**
- **existing operating brownfield assets.**

Even though expected and realized returns heavily depend on numerous factors specific to the individual project, the average return for these investments have decreased in recent years to single-digit return bands.⁶³ In some cases, investors reacted to this return compression by increasing the risk-profile of the investment in the form of increased country exposure (e.g., investing in emerging renewable energy markets with merchant power prices), increased technology risk (e.g., adding storage exposure to the original renewable energy proposition) or higher development risk.⁶⁴

In contrast to the above, Stafford believes that applying the full spectrum of optimization measures (including revamping and repowering) to aging renewable energy assets as discussed in [Chapter 1](#), in a growing repowering market driven by the forces described in [Chapter 2](#), creates an attractive alternative investment case for institutional investors in energy transition. Stafford believes these investments have the potential to deliver attractive double-digit returns with high cash-yields and additional non-financial benefits such as low carbon-intensity and a smaller land-use footprint compared to greenfield developments.

Stafford has successfully pursued such renewable energy asset optimization strategies, including revamping and repowering, in established markets since 2018. As such, we intend to continue creating corresponding investment opportunities for our clients in response to their interest in stable, cash-yielding infrastructure assets.

From a process point of view, an investor in a brownfield renewable energy asset with repowering potential would naturally strive to create financial and non-financial value while simultaneously de-risking the asset in each phase of the investment. The investment process starts with:

- Executing a comprehensive asset sourcing & acquisition strategy;
- After acquiring the asset, the operational performance needs to be improved through the swift and cost-efficient implementation of revamping, repowering, and other operational measures;
- In parallel to implementing the operational improvements, the capital structure of the plant (considering the additional capital expenditures for revamping and repowering) needs to be optimized;
- And finally, an exit at an enhanced exit-multiple on a portfolio-basis needs to be orchestrated towards the end of the intended holding period.

A strong track record in this kind of transaction, deep sector and technical knowledge, comprehensive project management skills, as well as an experienced and well-connected team in the applicable geographies are critical success factors for such investments.

Stafford believes that the investment case for repowering shows clear benefits in each step of the investment process.

3.1 Entry price benefits of repowering

A significant share of the installed renewable energy capacity with repowering potential is held by various (renewable energy focused) infrastructure funds. These funds usually have a 10-year term and an initial investment period of 3-4 years. Towards the end of their term, the focus of the respective manager is to realize the investments within the term of the fund. Often, the time and capital to further optimize the assets through repowering isn't available which provides an opportunity for a dedicated repowering investor to acquire the asset at an attractive valuation, including the upside from the repowering potential. In some cases, managers pursue so-called GP-led continuation fund transactions in which assets with repowering potential are being transferred from a fund not able to pursue the repowering to a newly created vehicle with available capital for the repowering investment.

⁶³ [European Negative Power Prices Highlight Merchant Projects Exposure - FitchRatings](#)

⁶⁴ [What risks are you taking in renewable energy? - Schroders](#)

However, these transactions come regularly with potential conflicts of interest which can be difficult to mitigate, and potentially increase the risk of not completing the transaction.

Besides infrastructure funds, many corporates own renewable energy assets of age with corresponding repowering potential, often as off-takers of the energy produced or for other strategic reasons. However, optimizing renewable energy plants, and more specifically revamping and repowering projects, regularly are non-core activities of such corporates which provides opportunities for a dedicated repowering investor to acquire such assets. This would include the embedded repowering potential.

These are just two examples of deal sources for a dedicated repowering investor and there are many other deal-flow opportunities that can be captured by an active sourcing approach. In any case, Stafford believes that given the similarities of these transactions to secondary transactions in areas such as infrastructure or private equity, a dedicated and experienced 'secondary specialist' across various asset classes with corresponding sourcing and evaluation process is clearly advantaged. Since inception in 2000, Stafford has been an experienced pioneer and dedicated investor in markets with secondaries characteristics like repowering.

3.2 Cash-flow benefits of repowering

Stafford believes that through the acquisition of a renewable energy asset with repowering potential, and after the successful implementation of the revamping, repowering, and other optimization measures, these assets can lead to earlier and stronger cash-flows through increased production.

This increased production through using existing structures and land can in return increase the actual performance ratios and result in higher revenues. This effect becomes even more apparent in cases of plants with high feed-in tariffs, demonstrating the importance of the country-specific assessment of the repowering attractiveness mentioned in [Chapter 2.5](#).

To show the cash-flow benefits of repowering more concretely, three real-life investment case studies of Stafford are compared below:

- 10 MW incentivized Solar PV operational plant without repowering (Brownfield)
- 10 MW incentivized Solar PV operational plant with repowering potential (Repowering)
- 50 MW non-incentivized Ready-to-Build (RtB) project.

Figure 11 below shows the three case studies which are represented in percentages of their respective total investment size for the purpose of comparability.

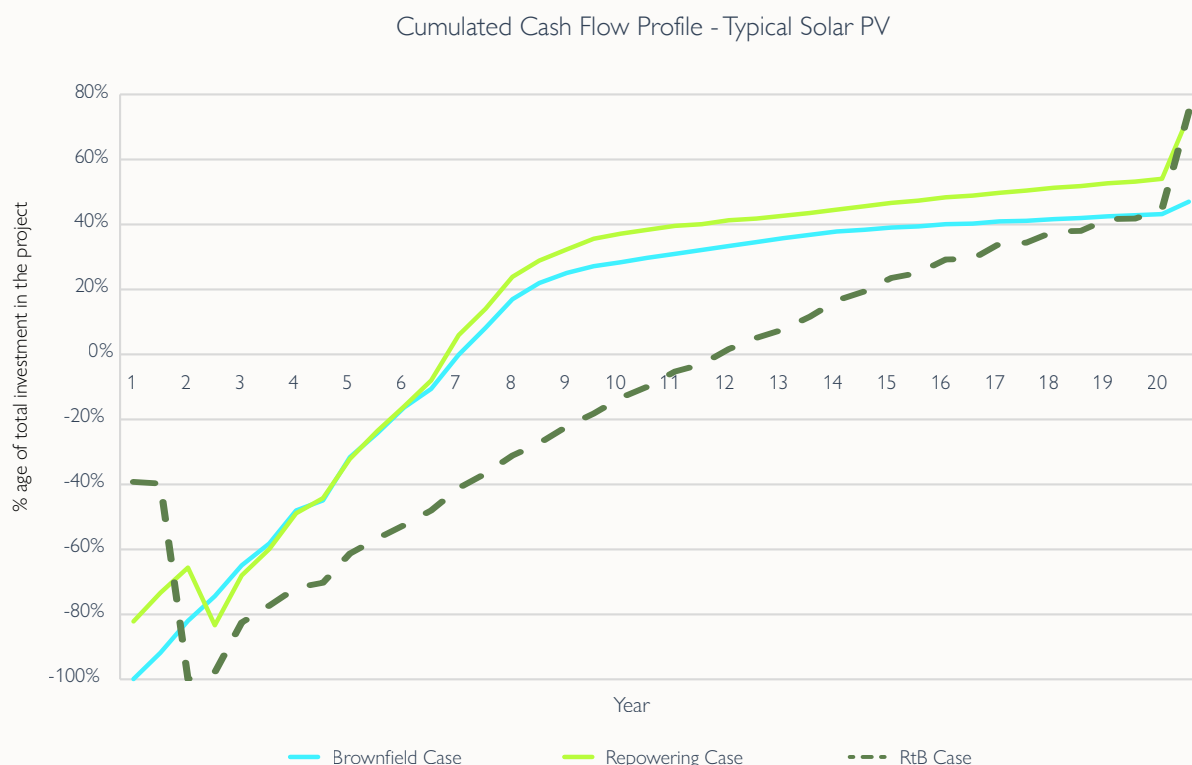


Figure 11: Comparison between Brownfield, Ready-to-Build and Repowering investment case studies⁶⁵

⁶⁵ Stafford proprietary analysis

In Stafford's experience, the RtB-case is currently the most prevalent case in the market. Although it typically allows for larger amounts to be deployed and has the potential to return a higher TVPI-multiple compared to the Brownfield case (due to its longer operational life), it generally achieves the cash-flow break-even significantly later. This is predominantly due to the extended time required for commercial operations to earn back the original investments as well as being amplified by the absence of incentives that generate relatively lower revenues in the initial years of investment compared to incentivized plants.

The analysis of these Brownfield and Repowering cases reveals not just a slightly quicker cash-flow break-even for the repowering investment, but also a more lucrative cash-flow upon exit given the prolonged lifespan of the facility. This effect is even more evident in Figure 12 showing the advantage of repowering in terms of higher generated cash-yield.

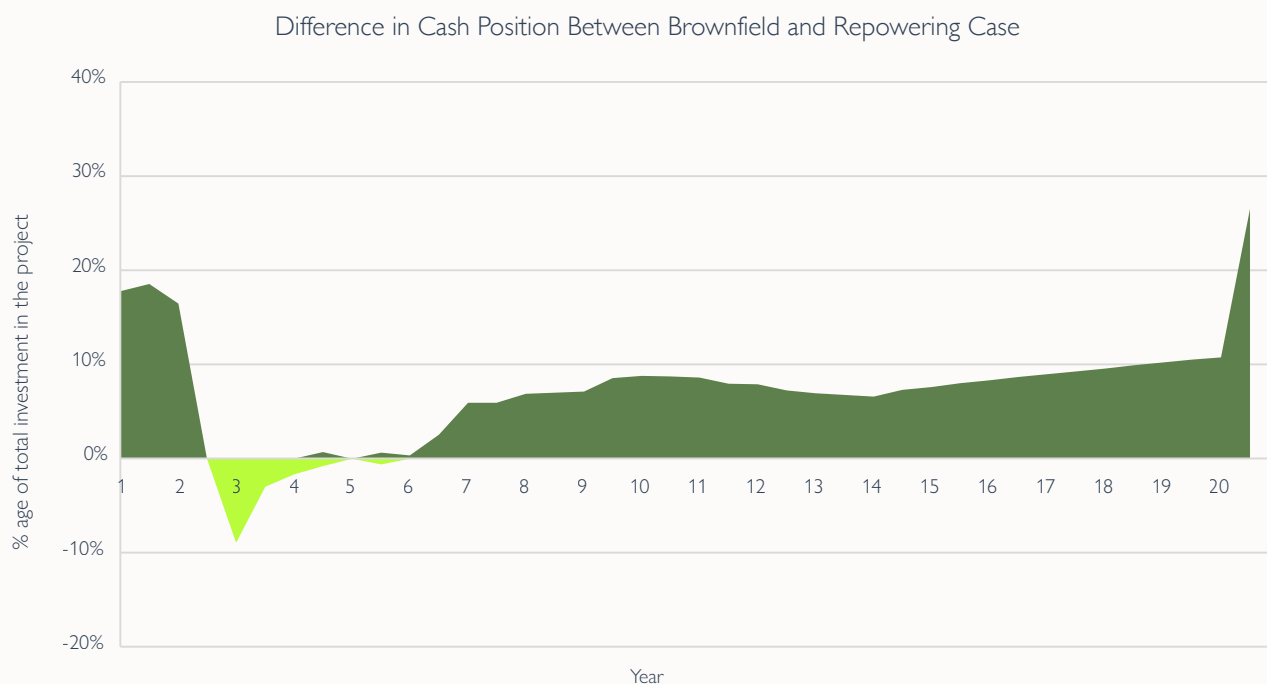


Figure 12: Cash-flow benefits Repowering versus Brownfield case study⁶⁶

3.3 Exit value benefits of repowering

Repowered plants enjoy an enhanced operational life through renewing and upgrading the equipment in use. This thereby reduces downtimes and malfunctions and ensures sustained profitability over time. These dynamics can lead to potentially higher exit values.

In the same context, enhanced bankability can be achieved. Repowering, applied to operating assets with a multi-year track record, provide a safer base for future production and revenue predictions to investors and lenders, increasing the potential exit value.

⁶⁶ Stafford proprietary analysis

3.4 De-risking benefits of repowering

The increased regulatory support for the repowering of aged renewable energy generation assets, as mentioned in [Chapter 2.5](#), is de-risking repowering investments with faster approval times and higher likelihood of success.⁶⁷

In addition, the fact that existing brownfield assets are already connected to the grid is another de-risking benefit of repowering, particularly in light of the 'grid challenge' described in [Chapter 2.2](#). The increased capacity achieved by a repowering project remains relatively small and therefore more digestible to the grid compared to adding a new RtB-project.

Repowering projects also come with a built-in buffer for process delays compared to greenfield developments. Delays at greenfield projects simply extend the time until first cash-flows occur. In contrast, for repowering projects the old equipment remains operative and cash-generative until all approvals have been granted, and the new equipment has arrived at the site.

Finally, when assessing repowering projects, site-specific information (such as the natural capacity of the plant) is more readily available and can show the plants operational capacity over multiple years of operation. This in turn can further de-risk the project.

3.5 Non-financial benefits of repowering

Besides the stronger financial performance of lower risk projects compared to greenfield projects, repowering may also provide significant non-financial benefits including better land-use efficiency, lower carbon-intensity, and in some cases improved shading and water-management.

3.5.1 Lower carbon intensity

We believe that repowering of photovoltaic and wind energy assets lowers their carbon intensity by re-using existing structures made from steel and concrete. Associated transformer stations, fences, access roads, etc. also remain in operation in contrast to a greenfield project in which all these components need to be newly built with corresponding carbon emissions attached.

3.5.2 Land-use efficiency

In Europe, land is generally a scarce resource. Repowering wind and PV may not only increase the energy output of wind farms and PV plants, but can also minimize their environmental footprint, thereby improving land-use efficiency.⁶⁸

In the case of wind power, the oldest wind farms are typically located at the most optimal wind sites but are often equipped with the least efficient turbines.⁶⁹ Repowering and revamping wind farms can bring particularly strong benefits by replacing outdated turbines with modern, more efficient models.

This practice not only leverages the already existing infrastructure, such as access roads and substations, but also benefits from pre-existing wind studies and data that validate the site's wind potential. Repowering ensures that the best wind resources are utilized to their full potential, aligning commercial interests with broader sustainability goals, thereby reducing the time and complexity associated with new site developments.

Similarly to wind plants, repowering of solar plants helps preserve the land (by increasing production on existing sites) and make better use of existing infrastructure.⁷⁰ In our view, the consequence is the increase of the installed capacity of PV plants, optimizing land use, without changing the footprint, and boosting the production up to 70%.

3.5.3 SDG-contributions and recycling

Stafford believes that repowering photovoltaic and wind energy plants is closely aligned with Sustainable Development Goals (SDGs) 7 (Affordable and Clean Energy) and 12 (Responsible Consumption and Production).

In terms of SDG 7, repowering directly enhances the efficiency and output of renewable energy systems and produces clean energy. After repowering, our analysis shows that a plant can reach up to 30-50% extra energy production transition to a more sustainable way to produce energy.

Furthermore, Stafford believes that repowering also promotes resource and energy efficiency, aligning with SDG 12 (Responsible Consumption and Production).

In particular, the use of existing infrastructure extends its operative life and reduces the overall waste production. Stringent recycling procedures enforced by the recycling partners for the respective components should be followed.

An often-overlooked issue of renewable energy is the treatment of obsolete components from older installations. As land-filling all existing wind turbines and solar panels doesn't seem to be an option, manufacturers and owners of renewable energy assets are working on alternative recycling and cradle-to-cradle concepts. Repowering with its inherent re-use of components of an existing renewable energy plant would seem to be well aligned with these efforts. Repowering projects increase the recovery of valuable materials, which can be reused or recycled into new components. Studies demonstrate that up to 90% of a wind turbine is recyclable.⁷¹

In addition, when photovoltaic panels reach the end of their economic life, they can still create value in other situations. For example, instead of disposing these panels, donating them to charitable organizations can help with the electrification of community centres, schools, and healthcare facilities, reducing their operational costs and allowing them to allocate more resources to their core missions.⁷²

⁶⁷ [Revised EU Renewables Directive set to speed up wind permitting - WindEurope](#)

⁶⁸ [Repowering Europe's wind farms is a win-win-win - WindEurope](#)

⁶⁹ [Why Repowering is key to wind power industry's growth - WindPowerMonthly](#)

⁷⁰ [Wind Repowering Helps Set the Stage for Energy Transition - US Department of Energy](#)

⁷¹ [Repowering existing Wind farms will help reach Renewable electricity targets faster - SIA-Partners](#)

⁷² [Old panels get second life in repurposing and solar recycling markets - Solar Power World Online](#)



4. CHALLENGES IN REPOWERING

4. CHALLENGES IN REPOWERING

Stafford's case for repowering as a key approach to increasing renewable power generation at attractive, risk-adjusted returns has been outlined. However, some challenges still need to be considered.

4.1 Extension of land-rights

Renewable energy assets aren't always built on owned-land but may have been leased by landowners under a long-term contract. The ability to either extend the lease agreement or acquire the land can represent a challenge in repowering as these renegotiations can arise earlier than expected under the contract and may provide strong negotiating leverage to the landowner.

4.2 Grid availability

Ensuring grid availability and compatibility is critical in repowering projects. This involves verifying that the upgraded systems and increased energy inputs can be seamlessly integrated with the existing grid infrastructure.

Coordination with grid operators is essential to ensure that grid connections are enhanced (when required) in line with the upgraded system's capacity. Advanced grid management technologies and storage solutions can be employed to balance supply and demand and integrate higher levels of energy into the grid.⁷³

4.3 Complexity of environmental regulations

Increased complexity of environmental regulations can present an additional challenge in repowering. This involves navigating an intricate array of local, national, and international regulations designed to mitigate environmental impact, ensure sustainability, and promote ecological conservation.

In solar, for example, the process of replacing older panels entails adherence to stringent disposal and recycling regulations to minimize the environmental footprint. The European Union's Waste Electrical and Electronic Equipment (WEEE) Directive mandates the recycling of PV panels, which involves the safe handling of hazardous materials such as cadmium and lead. In relation to windfarms, a repowering process must comply with all regulations concerning land use, wildlife protection, and noise pollution. In particular, the installation of larger turbines may require new environmental impact assessments (EIAs) to address potential effects on local fauna and flora, bird and bat populations, and community noise levels.

Regulatory frameworks such as the EU's Habitats Directive and Birds Directive require stringent assessments to mitigate adverse effects on biodiversity.

In addition, gaining local acceptance is critical for the successful repowering of PV and wind energy installations. This requires addressing community concerns regarding visual impact, noise, and environmental effects, and ensuring timely stakeholder engagement.

4.4 Integration of new technologies

The integration of new technologies into existing PV and wind energy systems during repowering poses significant technical challenges in retrofitting current installations with advanced components, while ensuring compatibility and maximizing performance.⁷⁴

In solar, for example, integrating newer, more efficient solar panels often requires the upgrading of related components such as inverters, mounting systems, and electrical infrastructure.⁷⁵ The challenge is in ensuring that these upgrades harmonize with the existing system architecture, as older components may not support the latest technological advancements. Furthermore, optimizing energy output while maintaining system stability and efficiency requires careful planning and often a complete re-engineering of system configurations.

As an example, in wind power, integrating new turbine models involves replacing outdated turbines with those of higher capacity and improved design. This upgrade often requires changes to foundations, tower structures, and grid connections. The increased size and capacity of modern turbines can lead to significant mechanical and electrical compatibility issues with the existing infrastructure. Additionally, new control systems and software must be integrated to manage the enhanced capabilities of the upgraded turbines.

⁷³ [Cables and Batteries - EIB](#)

⁷⁴ [Extending the Lifetime of Offshore Wind Turbines - MDPI](#)

⁷⁵ [Solar PV repowering: opportunities and challenges - NaturalPower](#)



5. CONCLUSION

5. CONCLUSION

Stafford believes that combining (1) the growing fleet of European renewable energy assets older than 10 years, the significantly decreased cost per megawatt for solar panels and wind turbines, and the rising footprint concerns with respect to greenfield developments, with (2) the experience and track record of a specialized repowering investor in replacing and upgrading such older renewable energy asset(s) results in an attractive and growing investment case for focused revamping and repowering at scale in Europe.

We believe there is an opportunity here to work existing renewable energy assets more efficiently, to support the growing demand for renewable energy generation whilst providing institutions with an investment opportunity that can help support their financial and non-financial objectives.



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