# Project EPIC

## Work Package 6:

## Network investment results for Use Case 3: Hybrid Heat Pumps

## Final Draft

EPIC

Energy Planning Integrated with Councils

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# 1. Glossary of Terms

| Abbreviation | Term |
|---|---|
| **BEZ** | Bath Enterprise Zone |
| **BU** | Bottom Up: Bottom Up analysis starts by modelling the load at individual distribution substations and aggregating up to HV feeder level. |
| **CAPEX** | Capital Expenditure |
| **CBA** | Cost Benefit Analysis |
| **DFES** | Distribution Future Energy Scenarios |
| **DNO** | Distribution Network Operator |
| **ENA** | Energy Networks Association |

| Abbreviation | Term |
|---|---|
| **ESA** | Energy Supply Area |
| **EPIC** | Energy Planning Integrated with Councils |
| **EV** | Electric Vehicle |
| **HV** | High Voltage |
| **HV NAT** | High Voltage Network Analysis Tool |
| **INM** | Integrated Network Model |
| **LCT** | Low Carbon Technology |
| **LV** | Low Voltage |
| **LV NIFT** | Low Voltage Network Investment Forecasting Tool |
| **MWh** | Megawatt Hour i.e. the energy used by consuming 1MW of power for an hour. |
| **NPC / NPV** | Net Present Cost / Net Present Value |
| **OPEX** | Operational Expenditure |
| **SPA** | Strategic Planning Area |
| **TD** | Top Down: Top Down analysis uses monitored HV feeder load profiles as a starting point to add the impact of LCT uptake. |
| **TOTEX** | Total Expenditure, the sum of all cost categories on either the network or society. |
| **WECA** | West of England Combined Authority |
| **WP** | Work Package |
| **WPD** | Western Power Distribution |
| **WS CBA** | Whole System Cost Benefit Analysis |
| **WWU** | Wales and West Utilities |

**Clarification on the meaning of 'Whole Systems'**

The project EPIC trial sought to consider the impacts of different investment strategies across the electricity and gas networks and on wider society. The term 'whole systems' has been used to reflect this intent, and appears throughout this report.

The results discussed do contain a whole systems element, with impacts on the electricity network and society being considered alongside each other. However, without gas network impacts incorporated into these results, 'whole systems' only constitutes these two stakeholders.

Further, there is the view that the term 'whole systems' should be reserved for analyses considering impacts from generation/production through transportation/storage, and on to end use. This goes far beyond the 'whole systems' results covered in this report.

The specific impacts considered in this report are detailed within section 4.1.3.

# 2. Document purpose and associated project deliverable

The Energy Planning Integrated with Councils (EPIC) Project trial is investigating the whole systems impact of a number of Low Carbon Technology (LCT) deployment strategies and investment approaches. Five use cases, set out in Work Package 2 (WP2) are being investigated, these are summarised in Table 1, below. Each use case passes results from High Voltage (HV) and Low Voltage (LV) network analysis tools, specified in WP4, through a Whole System Cost Benefit Analysis (WS CBA) tool. This WS CBA tool was developed outside of project EPIC by the Energy Networks Association (ENA) as part of their 'Open Networks" project, its specification and usage are detailed in WP3.

This document forms part of WP6 of the EPIC Trial. It describes the results of this whole systems cost benefits analysis for **Use Case 3**, assessing the impact on the network and society of a high deployment of hybrid heat pumps which allow heating systems to combine an electrically powered heat pump with a gas boiler and incorporates a control system to determine which energy source to use at any point in time. This flexibility of heating source enables the hybrid heat pump to shift demand from the electricity network to the gas network. In addition, a sensitivity considering the impact of a high uptake of a flexible use heat pump profile is tested.

*Table 1: The project EPIC Trial use cases*

| | |
|---|---|
| Use Case 1:<br><br>EV charger deployment | Comparing the network impact two EV charger deployment strategies, one with a greater reliance on LV connected on-street residential chargers, the other with a greater reliance on HV connected rapid charging hubs. |
| Use Case 2:<br><br>Energy Efficiency | Comparing the network impact of a high, low and medium standard of energy efficiency across residential and commercial customers. |
| **Use Case 3:**<br><br>**Hybrid Heat pumps** | **Exploring the impact of using the gas network and hybrid heat pumps to reduce peak electricity demand and electricity network costs.** |
| Use Case 4:<br><br>Just in Time vs. Fit for Future | Comparing a BAU network upgrade to meet immediate demand growth, or an investment in upgraded assets to meet longer term future demand growth. |
| Use Case 5:<br><br>Flexibility | Invest in an asset upgrade or contract a flexibility solution to delay or avoid the upgrade requirement. |
| Use Case 6:<br><br>Solar | Investigating the network impact of a higher deployment of large scale ground mounted solar. This is only tested in one Strategic Planning Area (SPA) (South Bristol) |

| Use Case 7: Heat Network | Exploring the whole systems impact of using a heat network to meet all heating demand from new developments in the SPA. This is only tested in one SPA (Bath Enterprise Zone). |
|---|---|

The analysis was conducted over three primaries, one in each SPA; Dorchester St, Nailsea and Cribbs causeway; this document describes the results on all three primaries. Not contained within this report are project learnings, which will be collated for all the use cases within the WP7 learnings report and largely focus on procedural and systemic learnings rather than conclusions drawn from individual results. More detailed discussion around individual LV and HV results, and their origins in network modelling assumptions, will be covered within the LV NIFT and HV NAT results which will be produced as part of WP5.

# 3. Key outcomes and conclusions

On all three primaries that were modelled in the trial, the high hybrid heat pump strategy results in 5-15% savings on HV network TOTEX. This is the expected result, with reduced demand from the electrification of heat resulting in lower overall network costs. The LV network is less impacted, with decreases in LV network TOTEX ranging from 1.5% on Nailsea primary, to 2.7% on Cribbs Causeway, and up to 3.1% on Dorchester St. This lesser impact on the LV network is consistent with results across the other use cases.

A reduction in electricity network related roadworks is captured, with up to 25-35% reductions in the societal cost of roadworks for the high hybrid HP strategy in Nailsea and Cribbs Causeway, and a 10-13% saving on the Dorchester St primary. Again, this is a natural result of having reduced future demand on the electricity networks.

This use case has demonstrated some unexpected impacts resulting from a large uptake of a flexible heat pump operating profile. The expected reductions in network expenditure resulting from decreased peak demands did not materialise. Instead, the high flex sensitivity resulted in up to 10% increases in network CAPEX. This is a result of modelling which has increased demand from heat pumps either side of the traditional peak, creating new peaks that are sufficient to cause constraints in some networks. This modelling is explored in more detail within the LV and HV modelling reports.

It is important to highlight that it is still expected that a high uptake of flexible heat pump operating profiles will, in practice, reduce demands on the network and associated expenditure.

This has been demonstrated by the FREEDOM[1] project where hybrid heat pump installations were trialled with sophisticated control systems enabling the selection between the gas boiler and heat pump to be optimised for minimising carbon footprint, minimising energy costs etc. As electricity at peak times tends to be more expensive and have a higher carbon intensity then under both cost and carbon minimising control regimes the heat pumps will naturally switch to gas operation, reducing the electricity demand on the network and the need for reinforcement. The limited availability of information about real operating profiles has resulted in profiles being used for modelling that may not be sufficiently sophisticated to represent the sophistication and flexibility of hybrid heat pump control systems. This use case has highlighted that the design of these ToU tariffs must consider secondary non-traditional peaks in demand resulting from their uptake; their design must be considered alongside other sources of flex demand, for instance, EV charging.

The modelling limitations are likely to have underestimated the benefits of hybrid heat pumps and so the savings may be higher than the 5-15% range and would be much higher than the predicted savings from energy efficiency. However the uptake of hybrid heat pumps comes with a greater degree of uncertainty and customers may be more inclined to adopt energy efficiency measures due to their greater familiarity. There is a need for greater understanding of the costs and benefits of hybrid heat pumps compared to introducing higher thermal storage capacity which may allow for reduced network loads at peak times without having dual energy supplies. It is not known if the elimination of gas boilers in new build properties will reduce customer's willingness to have hybrid systems due to concerns about future availability of boilers, parts or trained installation/ service staff.

## 3.1. Limitations of the modelling

1) While the intention of this use case was to compare the impact on the network and society of two heat pump deployment strategies, this has been difficult. Demand from new developments on the LV network has not been modelled in the high hybrid heat pump runs of HV NAT and, as a result, the true cost impacts of this strategy are not clear. Figure 1, below, describes this issue.

   While the true HV network costs of the high hybrid heat pump strategy are impossible to quantify at this stage, the trends discussed above (decreased HV network and roadworks costs for the high hybrid heat pump strategy) are still valid.

[1] https://www.wwutilities.co.uk/media/3860/freedom-project-final-report.pdf
*See also the July 2022 HyCompact project*

2) The nature of the Cost Benefit Analysis method also means that significant impacts in some cost categories appear insignificant when summed into a Network or Societal TOTEX impact, or further, into a whole systems Net Present Cost (NPC).

   The societal cost of emissions dominates the Societal TOTEX sum. This means that the demonstrated benefits of reduced roadworks from the high hybrid HP strategy do not result in a significant societal TOTEX percentage decrease. Similarly, when HV network costs are combined with LV and Societal costs into a whole system NPC, the demonstrated reductions in CAPEX and OPEX result in only marginal percentage decreases.

   In this use case, the whole systems impacts of the high hybrid HP strategy are almost all marginal. While Nailsea primary sees a maximum whole system saving of 2% for the high hybrid HP strategy, the other primaries see whole system savings below 2%.

3) It is also true that this use case has only investigated the impacts to and from the electricity network. The additional gas network costs to meet the demand of hybrid heat pumps has not been modelled. However, this could be expected to be not significantly higher than today peak gas load, as hybrid heat pump installations would be where gas boilers already exist and the overall reduction of gas load as boilers are replaced by electric heat pumps would still happen.
   The omission of gas network impacts from this whole systems CBA is discussed in this report and within wider project EPIC deliverables. As with the wider EPIC trial, this use case has highlighted the significant difficulties faced in modelling network impacts and integrating them into a whole systems cost benefit analysis. The results and learnings from this use case can be an aid to similar assessments in future.

4) The modelling of actual heat pump operation in a given set of buildings with known thermal characteristics, energy storage capacity, assumed weather data, assumed price and electricity carbon intensity values, occupancy patterns etc. would be able to better represent the likely heat pump energy consumption, however the costs and resource requirements associated with that level of modelling are beyond the scope of EPIC. The production of tools to simplify thermal modelling is one of the expected benefits of WPD's DEFENDER project.[2]

[2] https://smarter.energynetworks.org/projects/nia_wpd_065/

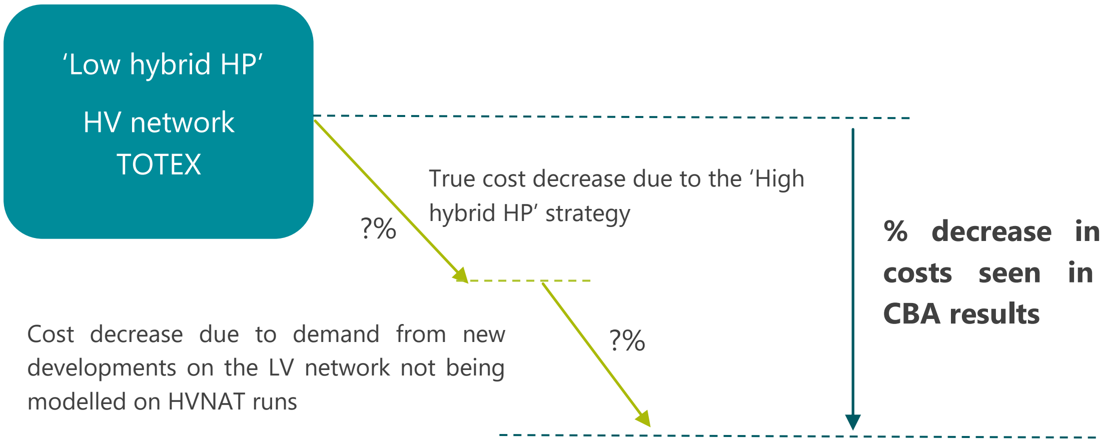


*Figure 1: Illustration of the impact of the 'high hybrid HP' strategy and the omission of demand from new developments on HV costs.*

*The High Hybrid HP strategy reduced HV TOTEX, as did the lack of new developments being modelled. The true TOTEX due to either of these factors is not known, the CBA results only show the total impact of both of these factors.*

# 4. Project EPIC background

The aim of the EPIC project is to develop a network planning process that considers impacts on both the electricity and gas networks and reflects the strategic ambitions of the local authority, enabling better investment outcomes. These outcomes may lower overall cost to the consumer, offer improved risk management and also enable local partners to realise their own strategic outcomes including net zero decarbonisation, economic growth, industrial strategy and wider societal benefits. A number of previous work package deliverables have documented in detail the process of the EPIC trial, the flow chart below summarises those work packages. In light of the progress of the trial process so far, the "integrated energy development plan" output has been replaced by results reports and a series of workshops with Local Authority stakeholders which will communicate findings and discuss their impact on local energy planning.

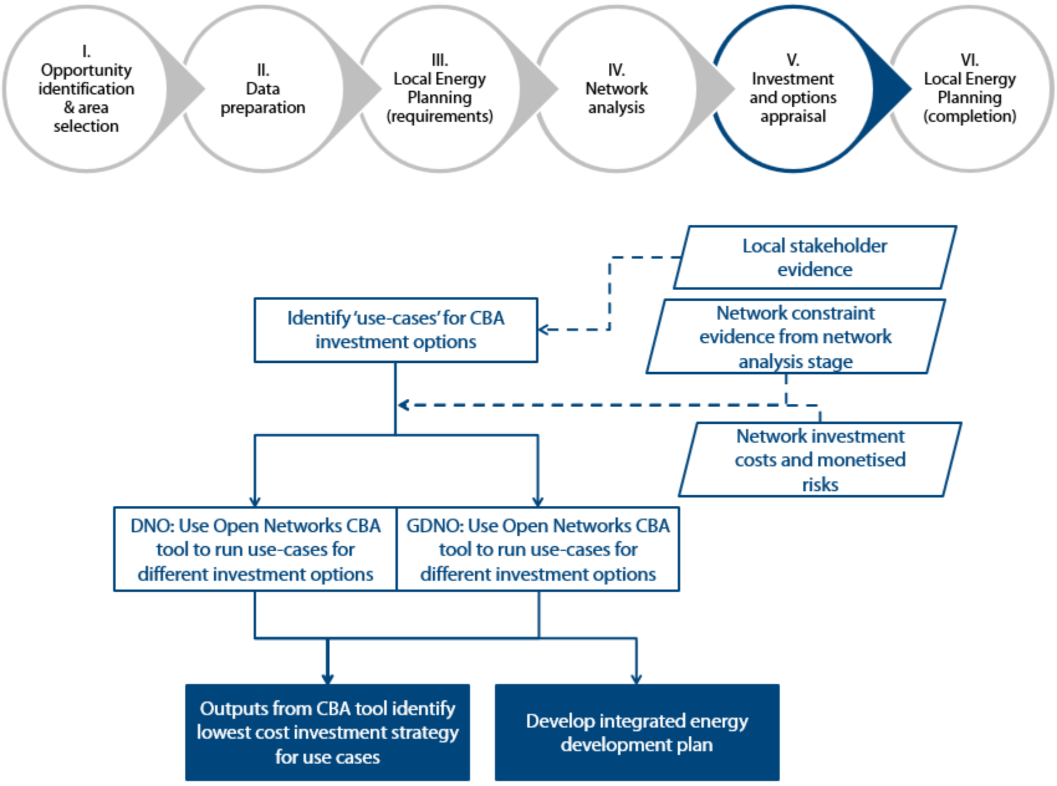


*Figure 2: The EPIC Trial Planning Process.*

## 4.1. Scope of the Whole System CBA

### 4.1.1. The Strategic Planning Areas (SPAs) and Primaries

The aim of the EPIC trial was to consider three SPAs selected in WP1, Bath Enterprise Zone (BEZ), the North Fringe and South Bristol. These were all served by multiple primary substations which were to be included in whole systems cost benefit analysis. At the time of the project, there was a change in the HV modelling tool used by WPD from DINIS to PSS SINCAL. This also coincided with a change in the way the network model to be used by the HV modelling tool was provided, with the creation of an Integrated Network Model (INM). This introduced a high risk that there would be issues with the network model that would take a long time to correct. To limit that risk, the decision was taken to model only a single primary within each SPA for the analysis. For the Bath Enterprise Zone, this was Dorchester St Primary. For the North Fringe, this was Cribbs Causeway Primary, and for South Bristol this was Nailsea Primary. While results for the LV network on the remaining primaries were generated, and have been used in the LV report to discuss trends across different areas, they do not feature in the whole systems CBA. Similarly, some of the initial work to create baseline profiles on the HV analysis included a wider range of primaries.

### 4.1.2. Gas network costs

Project EPIC faced a number of challenges in integrating gas and electricity network impacts into a whole system cost benefit analysis, these are described in more detail within the learning reports but came at a number of levels.

The initial approach taken to estimate future gas demand within each SPA was to work from 2020 WPD DFES projections. These projections take the baseline of existing gas boilers (~85% of households nationally) and add additional gas boilers from new developments between now and 2025 (based on new build EPC records). The conversion of existing gas boilers to heat pumps, heat networks, hydrogen boilers and other non-gas heating is based on assumed uptake rates of the different low carbon heating technologies. For instance, heat pump uptake is based on:

- **On-gas vs off-gas**, with much more near-term uptake in off-gas homes.
- **Floorspace**, with larger homes seeing greater heat pump uptake in the near term due to more space and higher heat demand.
- **Detached/semi-detached and owner-occupied homes** in the near term, mirroring analysis of existing RHI heat pump installations.
- **Insulation**, with homes with an EPC of C or above seeing greater uptake of non-hybrid heat pumps in the near term, and homes with an EPC of D or below seeing greater uptake of hybrid heat pumps.
- **Local authority feedback** that indicated a low carbon heat strategy gave higher weighting to heat pump uptake in the near term. For those with a specific heat network strategy, deployment of standalone heat pumps was weighted away from these areas in the near term.

The remaining on-gas homes were considered to switch from natural gas to hydrogen over the coming decades, and any remaining off-gas homes not accounted for by heat pumps, direct electric heating or night storage heaters would be assumed to be using a biofuel like bioLPG or biomass.

**This 'postcode level' approach had the potential to work as a way of assigning electricity and gas network costs to the SPAs, offering a suitable granularity in gas/electricity demand changes.**

However, it was found that the postcode data on the electricity and gas network did not match; there was no way of confidently unifying the two networks by postcode. This meant an approach had to be taken which used gas low pressure networks. These networks are far larger than an equivalent Electricity Supply Area (ESA), more akin to the size of a region (Bristol and Bath), they dwarfed the SPAs and did not provide sufficient granularity on demand changes of the gas network. Furthermore, the likely approaches to decarbonising the gas grid (eg. hydrogen and biomethane) are relatively large-scale, centralised approaches, which are less suited to the geographical granularity used. For instance the development of a biomethane production plant in the Bath SPA is not feasible, but it's possible that plant remote from the SPA could provide a supply of low-carbon gas.

The scenarios that were investigated resulted in small overall demand reductions on the gas network with increases from new developments being counteracted in the same area by reductions reflecting the move from gas boilers to electric heat pumps. This resulted in a lack of reinforcement requirements but at the same time the reductions did not suggest decommissioning of assets would be a useful cost saving option either. While work has been completed in developing separate scenarios to test the process of modelling gas network upgrades, reflecting the work required to support hydrogen networks, this has also proved challenging. The gas network analysis tool does not export cost outputs, instead, the costing of solutions is a distinct activity carried out on a specific basis per project; further work on costing these solutions would have to take place before any inclusion in a whole system CBA. However, analysis and cost outputs were generated through a manual approach, so gas network impacts can be covered by the EPIC process in future.

### 4.1.3. Cost Categories and CBA Process

The HV analysis was carried out by the HV Network Assessment Tool (HV NAT) developed by PSC and the LV analysis was provided by EA Technology using the Network Investment Forecasting Tool (NIFT). Work earlier in the project to determine which whole system costs could be considered by the network analysis tools arrived at the list of direct network and indirect societal impacts given below. Where necessary, these impacts have been monetised using calculations presented in the WP3 deliverable.

- **CAPEX:** Expenditure on asset intervention on the LV and HV networks.
- **LV OPEX:** Expenditure on LV network operation.
- **HV flexibility requirement (OPEX):** The total volume of flexibility needing to be procured on the HV network, valued at £300/MWh, as a measure of HV operating costs.
- **Losses:** Electrical losses on the HV and LV network, valued at £62/MWh.
- **Roadworks:** Number of instances of asset intervention which require roadworks. This is considered both as a direct cost for the Distribution Network Operator (DNO) at £244/instance, and indirectly on society at £1332/instance.
- **Final Demand (emissions):** The final demand met by the HV network and its associated emissions impact on society. This is valued using assumed grid carbon factors, and a societal value of carbon.
- **Spare Capacity:** The value to society of extra network capacity unlocked by network CAPEX intervention, resulting in cheaper connections. The valuation is based on an average cost per MW of LV and HV network: £199k/MW for the LV network, £298k/MW for the HV network.

Important to the estimation of the Net Present Cost (NPC) of each strategy was the provision of these costs on an annual basis out to 2050. This was possible on the LV network from LV NIFT. On the HV side, HV NAT output annual increments up to 2035, followed by five-yearly increments out to 2050.

Within the CBA tool, these costs are allocated to either the networks or to society. The diagram below outlines this allocation:

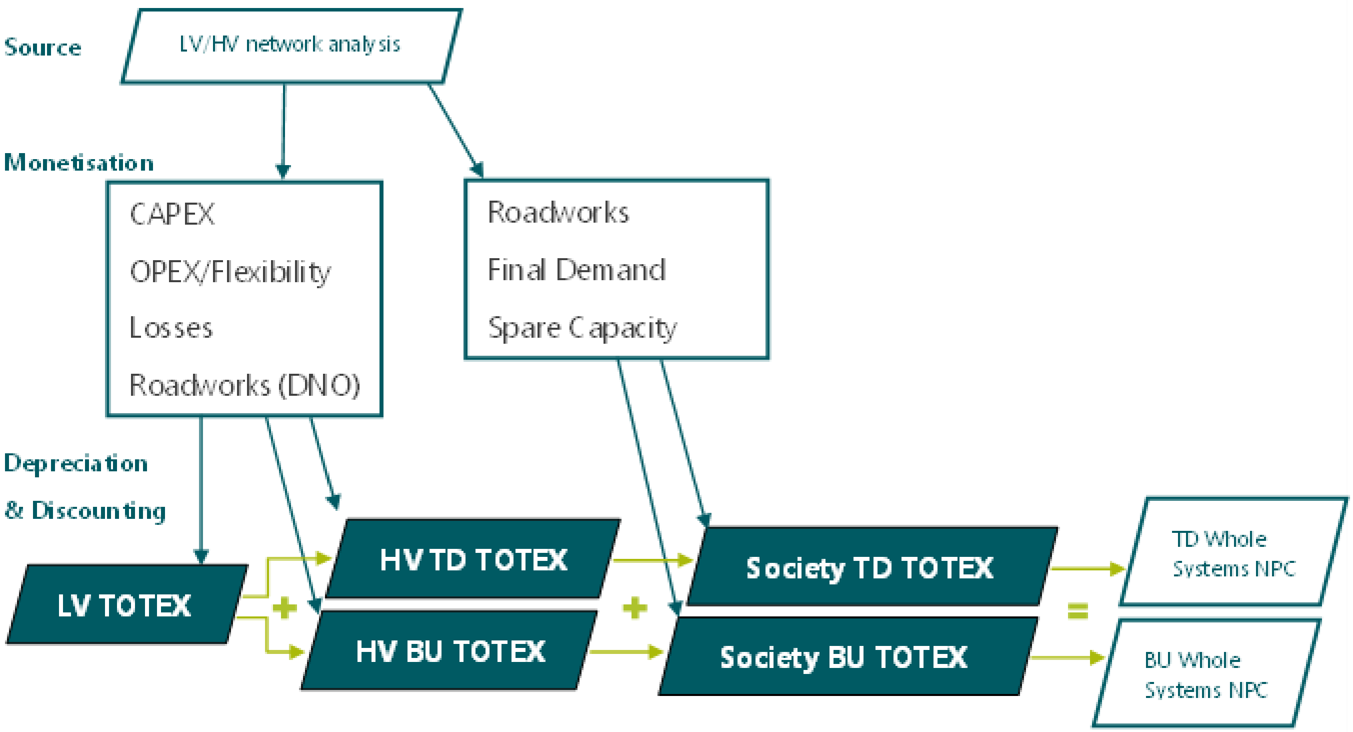


*Figure 4: The processes involved in generating results from the WS CBA tool.*

The diagram also illustrates how Top Down (TD) and Bottom Up (BU) analysis[3] of the HV network are considered. These two methods of analysis have produced separate results for the HV network which result in distinct societal and whole systems costs. The requirement for both Top Down and Bottom Up analysis reflects the different sources of data available and different approaches to planning for both HV and LV networks. Primary substations typically have monitoring installed at the 11kV feeder circuit breakers but most distribution substations are not monitored. Therefore while the total feeder load is know the loads at different distribution substations are estimated by pro-rating the total load, typically by transformer rating. Thus loads are allocated in a "Top-Down" method when modelling the HV networks. While this method has the advantage that the sum of the distribution loads will equal the monitored load for the feeder, it has the disadvantage that shape of the profiles at the distribution substations are all the same, rather than reflecting the particular mix of customers on that substation.

However when modelling LV networks estimated loads would be built up from knowledge of

[3] Top Down analysis uses monitored HV feeder load profiles as a starting point to add the impact of LCT uptake whereas Bottom Up analysis starts by modelling the load at individual distribution substations and aggregating up to HV feeder level.

the connected customers for that substation and profiles for typical customer types. Adding expected customer loads would provide profiles at the distribution substation level that should be more accurate in terms of profile shape but may not sum together along the feeder to equal the observed load at the source circuit breaker. Currently there are advantages and disadvantages for both top-down and bottom-up approaches but over time, as more distribution substations are monitored and smart meter data informs the estimated load profiles at distribution substations, it is likely that the bottom-up approach will become more accurate and will inform HV modelling.

The CBA tool applies depreciation to CAPEX, sums annual costs into TOTEX and discounts the value of future costs in line with best practice in network investment planning and government guidelines. Summing the TOTEX values for the LV network, HV network and society gives a whole system NPC for each tested strategy.

# 5. Results – Use Case 3: Hybrid Heat Pumps

The results below convey the final iteration of network analysis runs which were able to be conducted in the timescale of the EPIC trial process. Early runs of network analysis identified results which were not consistent with expectations. The processing of the CBA results helped sense check modelling assumptions and modifications to the HV model were followed by subsequent iterations of results, the WP7 learning report documents this in more detail. Examining all specific results and trends in detail has not been possible and so results are discussed where specific information has been available.

This use case assesses the impact on the network and society of a high deployment of hybrid heat pumps and a high uptake of a flexible use heat pump profile. Hybrid heat pumps are assumed to provide heating using the gas network (rather than electricity) on the peak winter and intermediate cool days, thus limiting the increase in demand on the electricity network. The flexible heat pump operating profile assumes that the heat pump responds to higher prices in periods of traditional network peak demand by pre-heating the home prior to the morning and evening peak. This leads to higher demand during the middle of the day compared to the unabated profile, but no demand during the peak periods on the winter representative day. This is a very simplistic assumption of how flexible heat pumps would likely operate in practice.

This use case compares three combinations of these variables:

1) Low uptake of hybrid heat pumps & low uptake of the flex profile.
2) High uptake of the hybrid heat pumps & low uptake of the flex profile
3) Low uptake of hybrid heat pumps & high uptake of the flex profile.

Table 2 below describes the structure of the comparisons made in this report. While absolute costs have been calculated for each strategy, the focus of the report is on the relative costs/benefits of the different strategies and these will be expressed as percentages of the reference strategy.

In this case, **the reference strategy is the "Low Hybrid HP, low flex" variation**, and **percentage increases or savings** for the **"High Hybrid HP"** strategy and **"High Flex"** sensitivity will be reported.

*Table 2: The Hybrid HP strategies and sensitivities being tested in Use Case 3 and impacts discussed in this report.*

| | Strategy 1: **Low Hybrid HPs** (reference strategy) | Strategy 2: **High Hybrid HPs** |
|---|---|---|
| Sensitivity 1: Low flexible use tariff | N/A - Reference strategy | % change in costs/benefits |
| Sensitivity 2: High flexible use tariff | % change in costs/benefits | N/A – not tested |

Table 3, below, illustrates the relative impact of the high hybrid HP or high flex profile deployment on all cost categories. Grey cells cover those cost categories which have marginal (less than 2%) changes in overall cost between strategies/sensitivities. Those cost categories which do see some variation, 2 – 10%, are highlighted in orange, while variations over 10% are highlighted in red. Even greater impacts, over 50%, are indicated by black cells. What is immediately clear is the regularity of significant impacts on the electricity network, with the occasional impact over 50% and the relative lack significant societal impacts. When costs are summed into TOTEX and whole system costs, shown in table 4, the networks do see some significant impacts, but whole systems impacts are rare.

*Table 3: Results overview for each cost category on each primary.*

| | CAPEX | | | OPEX | | | Losses | | | Roadworks | | | Emissions | | | Spare Capacity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LV | HV BU | HV TD | LV | HV BU | HV TD | LV | HV BU | HV TD | LV | HV BU | HV TD | LV | HV BU | HV TD | LV | HV BU | HV TD |
| Dorchester St | Orange | Red | Red | Orange | Orange | Orange | Grey | Grey | Grey | Red | Orange | Red | Grey | Grey | Grey | Grey | Orange | Grey |
| Cribbs Causeway | Orange | Orange | Red | Orange | Red | Black | Grey | Grey | Grey | Red | Red | Red | Grey | Grey | Grey | Grey | Grey | Grey |
| Nailsea | Orange | Black | Red | Red | Red | Red | Orange | Grey | Grey | Red | Red | Red | Grey | Grey | Grey | Orange | Orange | Grey |

*Table 4: Results overview for TOTEX and whole systems cost on each primary.*

| | TOTEX | | | | | | |
|---|---|---|---|---|---|---|---|
| | LV | HV BU | HV TD | Societal BU | Societal TD | WHOLE SYSTEM BU | WHOLE SYSTEM TD |
| Dorchester St | Orange | Orange | Orange | Grey | Grey | Grey | Grey |
| Cribbs Causeway | Orange | Orange | Orange | Grey | Grey | Grey | Grey |
| Nailsea | Orange | Red | Red | Grey | Grey | Orange | Grey |

| |
|---|
| Less than 2% difference in costs between strategies |
| 2 - 10% difference in costs between strategies |
| Over 10% difference in costs between strategies |
| Over 50% difference in costs between strategies. |

For those highlighted instances where there is over 2% difference in a cost between the strategies, the results are summarised below and illustrated graphically in Appendices 1-3.

Additional explanation is given for those costs where a 50% or greater variation is observed.

## 5.1. CAPEX

### 5.1.1. Dorchester St

The High Hybrid HP strategy results in 4% savings LV CAPEX out to 2050. This is driven by significant savings in 2020, 2031 and 2034. Its impact on HV CAPEX is greater, resulting in 14-16% savings though large savings in individual years post 2030.

This is the result that was expected, with hybrid heat pumps reducing demand on the electricity network and so leading to reduced CAPEX requirements. For these particular primary sub-stations, the LV network is the first to see the CAPEX reductions, mainly coming in the near term and out to 2035. The HV network sees CAPEX impacts from 2030 onwards.

The high flexible use strategy results in 4% increases in LV CAPEX out to 2050. On the HV network this increase is also present but to a lesser degree, at just 2%. This result was **not expected**, with the flexible use tariff designed to ***reduce*** peak loading on the networks and associated CAPEX. The individual annual CAPEX increases which cause this are almost all post-2030, and in the case of the LV network, focus on two individual years, 2035 and 2040.

This unexpected result comes out of modelling which has increased demand from heat pumps either side of the traditional peak creating new peaks that are sufficient to cause constraints in some networks. In reality, if new peaks were created then it would be expected that these would have the same high costs and carbon intensity that were associated with the peak they replaced and that the control systems and flexible tariffs would adjust to flatten these new peaks resulting in flatter demand profiles and reduced reinforcement requirements. This modelling issue is explored in more detail within the LV and HV modelling reports. It is important to highlight that it is still expected that a high uptake of flexible heat pump operating profiles will, in practice, reduce demands on the network and associated expenditure.

### 5.1.2. Cribbs Causeway

LV CAPEX is impacted by the high hybrid HP strategy similarly to Dorchester St, with a 5% capital cost saving. On the HV network, the impact is smaller, with just a 2% saving from bottom up analysis. In this case however, the top down method produces a 35% saving. With these two contrasting results it is difficult to assess the impact of the high hybrid HP strategy on HV CAPEX.

The high flexible use tariff again increases network CAPEX, but to a very small (<1%) degree on the LV network, and just a 3% increase on the HV network. While this is the same unexpected upward impact as seen on the Dorchester St primary, the relative impacts on the LV versus the HV network are reversed, with the greater impact this time being on the HV side.

## 5.1.3. Nailsea

On the Nailsea primary, the downward impact of the high hybrid HP strategy on network CAPEX is maintained. In this case the LV network sees 4% savings, and the HV network sees a very large 55% saving based on the bottom-up analysis:

**The hybrid HP strategy prevents the need to split a feeder in 2040, and upgrade a primary transformer in 2045**

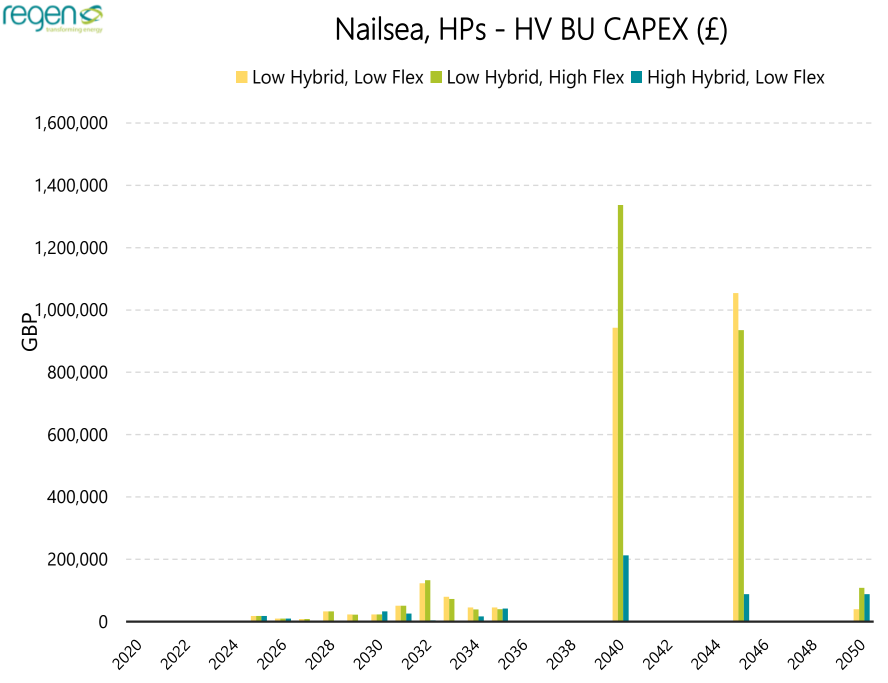


*Figure 5: HV CAPEX on the Nailsea Primary out to 2050, from bottom up analysis.*

The top-down analysis produces a more modest 14% saving. Again, the LV network sees these savings earlier, from 2030 onwards.

The high flex strategy is again acting to increase network CAPEX, and to a slightly larger degree than the other primaries. A 5% upwards impact on LV CAPEX and a 10% upward impact on HV CAPEX.

## 5.2. OPEX

OPEX results are highly dependent on the number of smart solutions being deployed by the LV NIFT and HV NAT models. It has not been possible to investigate specific results and interrogate where smart solutions have been deployed. However, as a constraint may be resolved with a smart solution, which has small CAPEX but large OPEX, or a traditional network asset intervention which will have large CAPEX and small OPEX, it can be assumed that strategies with an upwards OPEX impact have deployed more smart solutions.

## 5.2.1. Dorchester St

In terms of OPEX, on this primary, the LV and HV network are both similarly impacted by the high hybrid strategy. The high hybrid strategy decreases LV CAPEX by 7% and HV CAPEX by 5%. The trend seen in on other primaries for greater impact on the HV network is not present.

The high flexible use tariff has an interesting effect on network OPEX. On the LV network it aligns with the trends seen in CAPEX by increasing LV OPEX by 3%. However, on the HV network it leads to a marginal decrease in OPEX, this is the only instance on this primary where the high flexible use tariff leads to cost reductions.

## 5.2.2. Cribbs Causeway

On the LV network on this primary, a saving of 3.5% is delivered by the High Hybrid HP strategy. A far larger saving of 20% is present on the HV network, and this increases to 60% if a top down approach is used:

**The high deployment of hybrid HP's and the lack of LV new developments demand captured in the high hybrid runs has resulted in less assets experiencing overload conditions and trigging an OPEX service (8 assets vs 33 assets).**

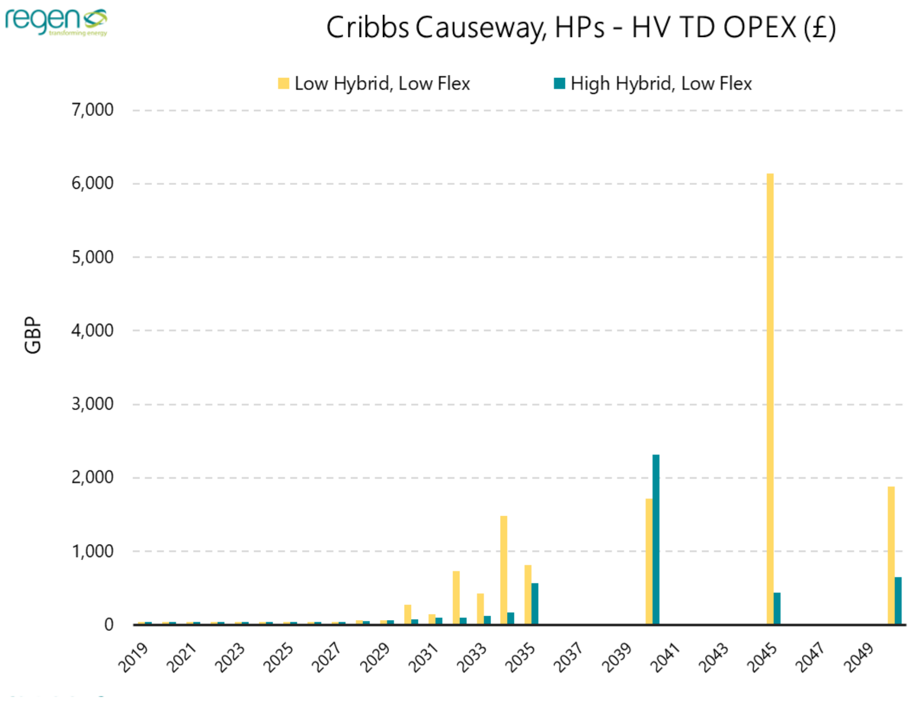


*Figure 6: HV OPEX on the Cribbs Causeway Primary out to 2050, from top down analysis.*

These large OPEX savings align with the also significant CAPEX savings seen on Cribbs Causeway.

The high flex strategy has marginal impact on LV OPEX, but a large 30% upward impact on HV OPEX. This large HV OPEX increase is not seen on the other primaries where the low flex strategy leads to HV OPEX savings.

### 5.2.3. Nailsea

The high hybrid strategy results in a small saving in LV OPEX, a similar scale to its impact on LV CAPEX. Similarly, the large impact seen on HV CAPEX is mirrored in HV OPEX with a 30% saving from bottom up analysis.

The high flex strategy has a significant downward impact on network OPEX, a 20% saving on LV OPEX and a 10% saving on HV OPEX. These are both the reverse of the CAPEX increases seen on this primary from the high flex strategy.

## 5.3. Losses

### 5.3.1. Nailsea

The only significant impact seen on losses came on the LV side of the Nailsea primary. The high hybrid HP strategy leads to an overall 3% saving in LV losses. This is all delivered post 2025.

## 5.4. Roadworks

### 5.4.1. Dorchester St

The roadworks results on this primary align with the CAPEX results, with the high hybrid strategy having a downward impact on roadworks and being more impactful on the HV network, and the high flexible use tariff increasing roadworks while having greater impact on the LV network.

### 5.4.2. Cribbs Causeway

Roadworks are also decreased on the Cribbs Causeway primary by the high hybrid strategy. The LV network is less heavily impacted, with a 16% saving resulting from a 5% CAPEX saving. The HV network sees a 35% saving from a 2% CAPEX saving from bottom up analysis.

This is also the trend seen with the high flex strategy, with zero impact on LV roadworks and a 15% increase in HV roadworks arising from a 3% CAPEX increase.

### 5.4.3. Nailsea

On the Nailsea primary a different trend is seen, with LV roadworks seemingly more influenced by changes in CAPEX. A 15% saving in roadworks results from a 4% drop in CAPEX. While the CAPEX impact on the HV side is a large 55% saving, the roadworks decreases by 30%. This is also seen from the high flex strategy, with roadworks increases.

As identified in the other use case reports, Nailsea has an LV network with a longer average feeder length than the other two primaries. This makes LV roadworks particularly sensitive to CAPEX interventions.

## 5.5. Emissions (Final Demand)

Emissions impacts are estimated using final demand values from HV analysis and an assumed reducing grid carbon factor. The results across all three primaries indicate a marginal emissions impact for the high hybrid HP strategy and the high flex profile.

Dorchester St sees 0.45% reductions, Cribbs Causeway 0.20% and Nailsea 0.6%. The grid carbon factor, which is assumed to decrease relatively linearly from 0.3 tonnes/MWh to zero by 2050, does contribute to these low figures; If a fixed carbon factor is assumed, the result for Nailsea would be a 1.6% decrease.

It is worth noting that despite these marginal impacts, the monetisation method applied to emissions (based on the social cost of carbon) leads to high absolute cost differentials when viewed against the other cost categories. For example for the High Hybrid HP strategy on Cribbs Causeway, a 0.2% reduction in emissions represents a £140k saving to society. In comparison, a 35% saving in HV CAPEX represents a £900,000 saving to the network.

## 5.6. Spare Capacity

The method of assessing spare capacity did not result in any significant differences between the strategies. It is suspected that the large 2019 CAPEX interventions played a role in making any subsequent CAPEX interventions and their additional spare capacity benefit negligible.

One of the only non-marginal impacts on Spare Capacity comes from the bottom up analysis of the HV network, here the high hybrid HP strategy reduces Spare Capacity benefit by 2.5%.

## 5.7. TOTEX

Summing the above cost categories produces TOTEX values for the LV and HV network. Societal TOTEX is comprised of roadworks, emissions and spare capacity.

As described above there are negligible differences between the Spare Capacity delivered by the different strategies. The scale of the emissions valuation described above means that the societal TOTEX sum is dominated by emissions. The negligible changes seen in emissions between strategies, means that the Societal TOTEX sums all present negligible societal impact. This is despite there being identifiable benefits being delivered through reduced roadworks.

### 5.7.1. Dorchester St

Being largely driven by network CAPEX impacts, the Network TOTEX impacts follow the same trends to those discussed in the CAPEX section. The High Hybrid HP strategy has a small downward impact on LV TOTEX (3%), the HV network is again slightly more impacted, with a 5-7% decrease. The high flex strategy has a marginal upward impact on network TOTEX.

For the reasons discussed above there is no significant quantitative impact on societal TOTEX. However the high hybrid HP strategy resulted in 10-12% fewer roadworks from network intervention.

### 5.7.2. Cribbs Causeway

The HV network is most impacted by the high hybrid HP strategy, with 10% TOTEX savings. The LV network by comparison sees 2.5% savings. On both networks the high flex sensitivity has negligible upward impact on network TOTEX.

As with the other primaries, there is no significant quantitative impact on Societal TOTEX. However the high hybrid HP strategy resulted in 25-35% fewer roadworks from network intervention. A significant result.

### 5.7.3. Nailsea

On the Nailsea primary the HV network sees the largest TOTEX saving of all the tested primaries, at a 10% - 15% saving. Interestingly, on the LV network, the high flex sensitivity is more impactful than the high hybrids strategy, resulting in a 3% saving (this driven by an OPEX saving and is the only instance of the high flex sensitivity resulting in a significant TOTEX impact, it is also the only instance of the high flex sensitivity resulting in a TOTEX saving).

As with the other primaries, there is no significant quantitative impact on societal TOTEX. However the high hybrid HP strategy resulted in 20-25% fewer roadworks from network intervention. A significant result.

## 5.8. Whole Systems - one significant (over 2%) impact

The nature of the Cost Benefit Analysis method means that significant impacts in some cost categories appear insignificant when summed into a whole systems Net Present Cost (NPC); the Nailsea Primary was the only primary to see a significant result here – A 2% saving for the high hybrid HP strategy.

# 6. APPENDIX 1: Dorchester St significant results

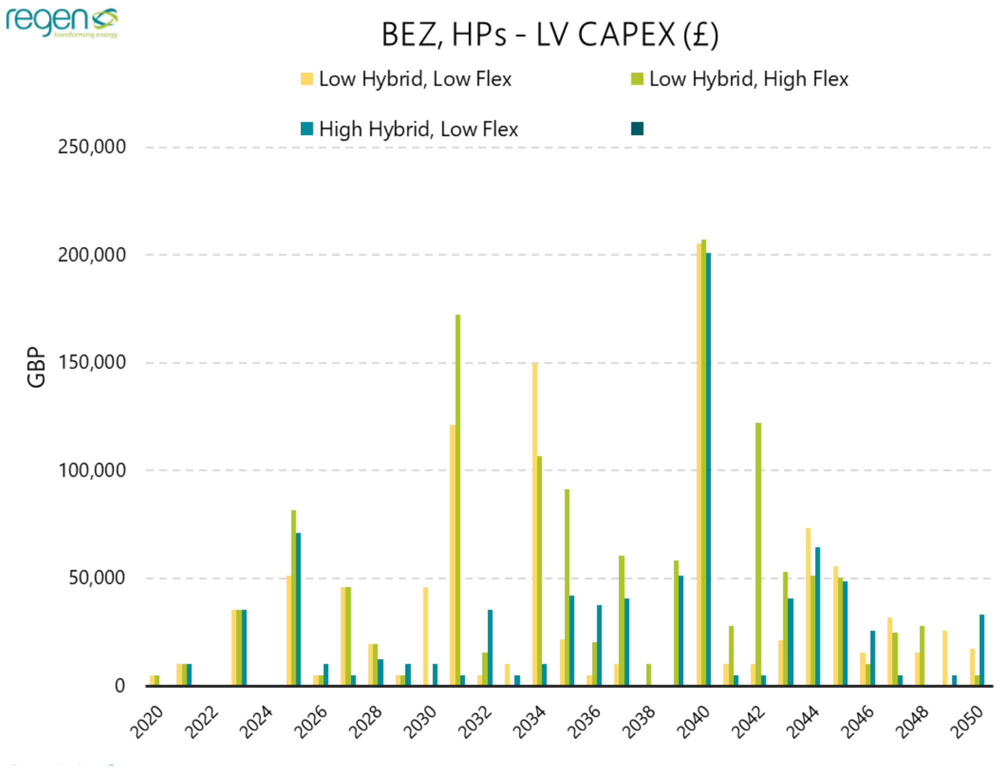


*Figure 7: LV CAPEX by year on the Dorchester St Primary*

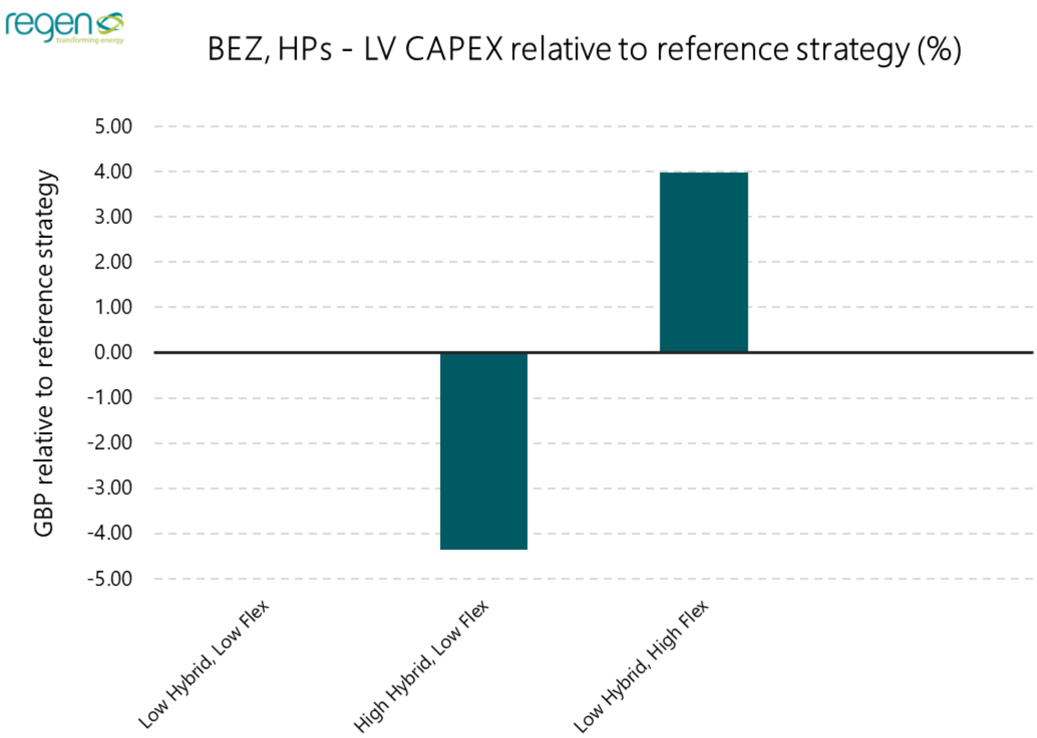


*Figure 8: Total LV CAPEX by 2050 on the Dorchester St Primary*

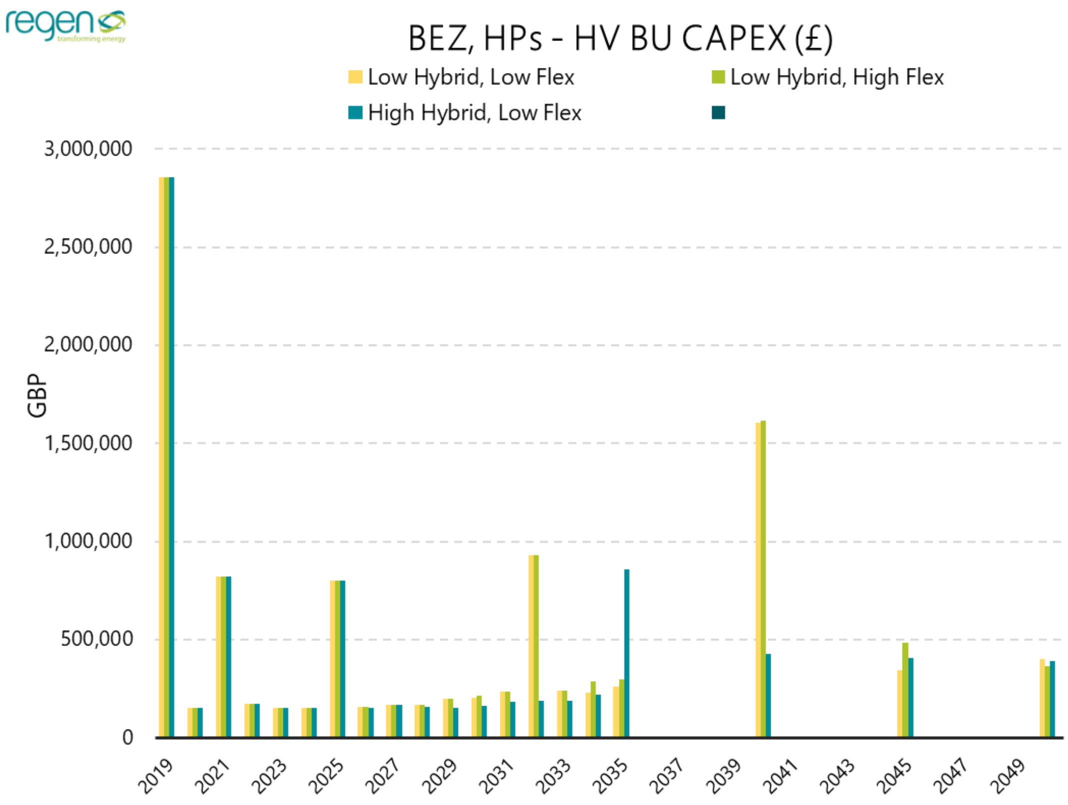


*Figure 9: HV CAPEX by year on the Dorchester St Primary, from bottom up analysis*

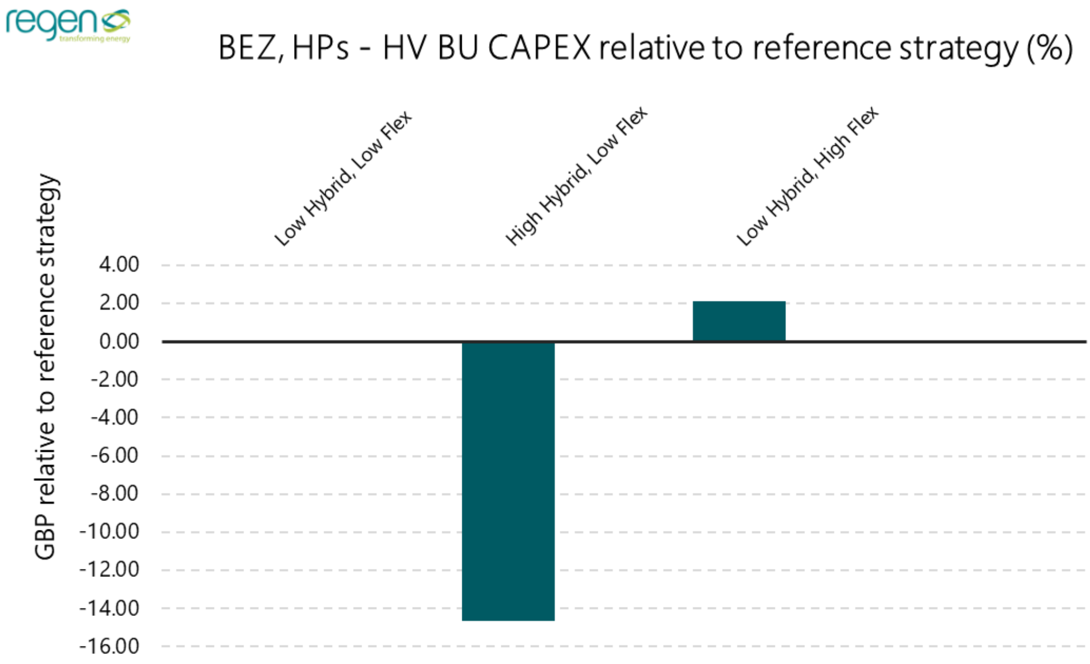


*Figure 10: Total HV CAPEX by 2050 on the Dorchester St Primary, from bottom up analysis*

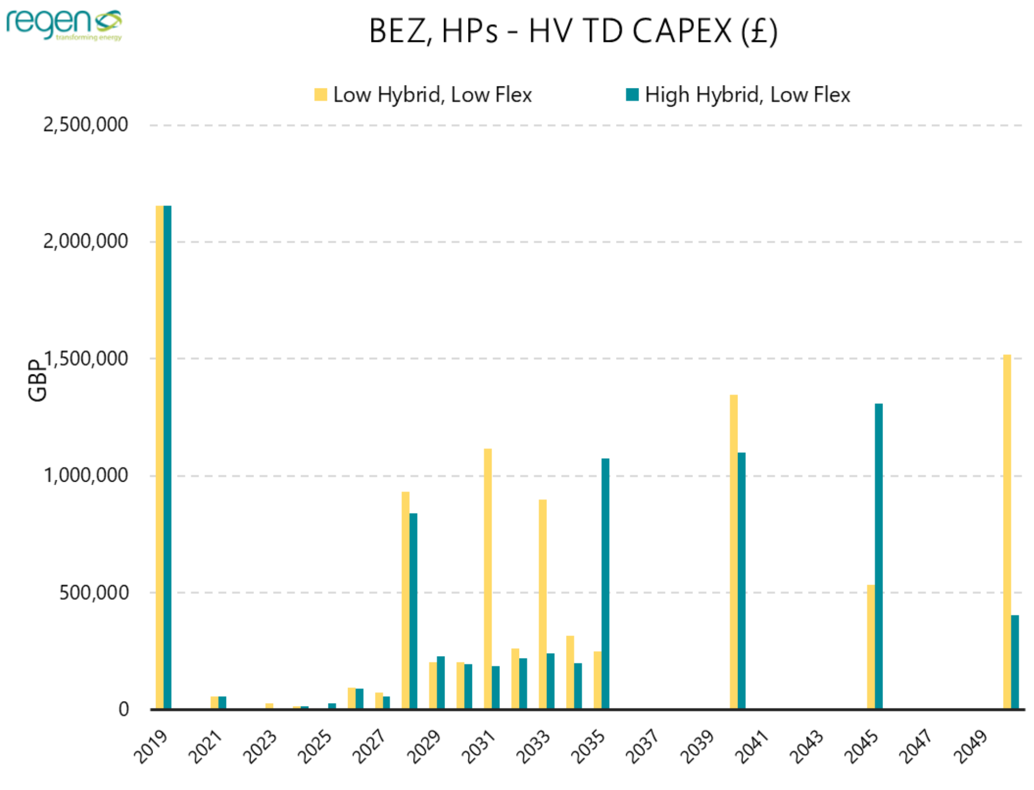


*Figure 11: HV CAPEX by year on the Dorchester St Primary, from top down analaysis*

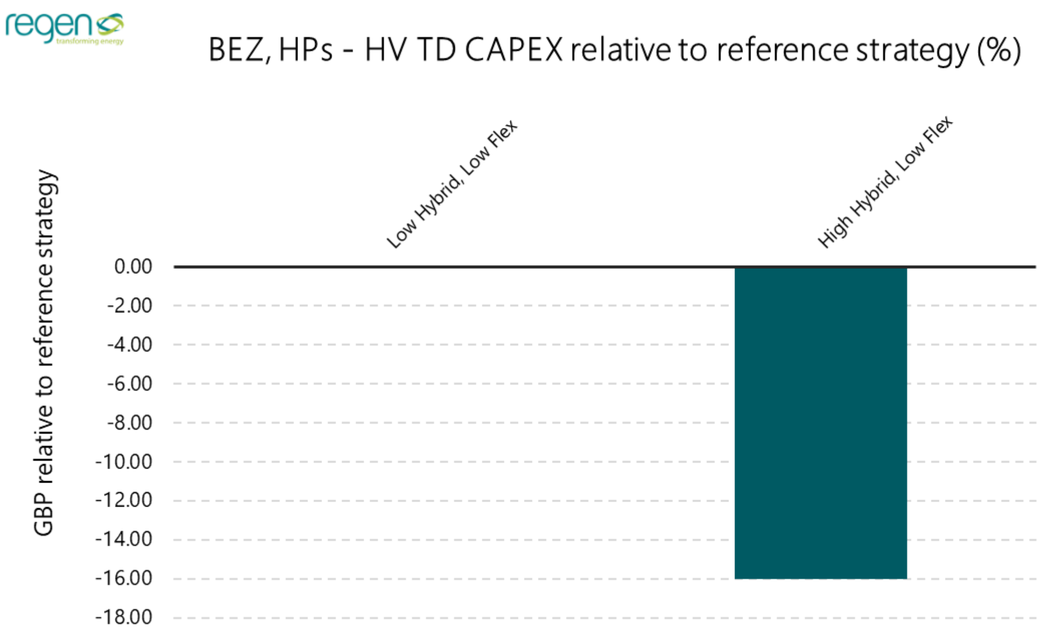


*Figure 12: Total HV CAPEX by 2050 on the Dorchester St Primary, from top down analaysis*

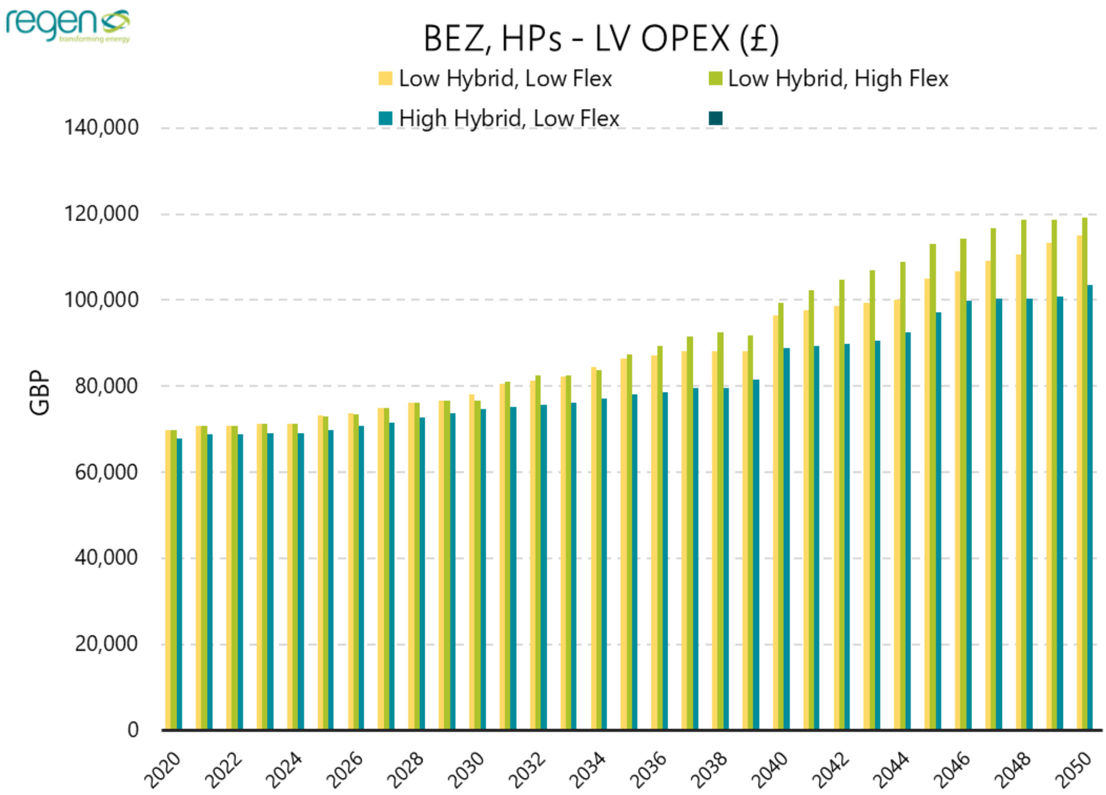


*Figure 13: LV OPEX by year on the Dorchester St Primary*

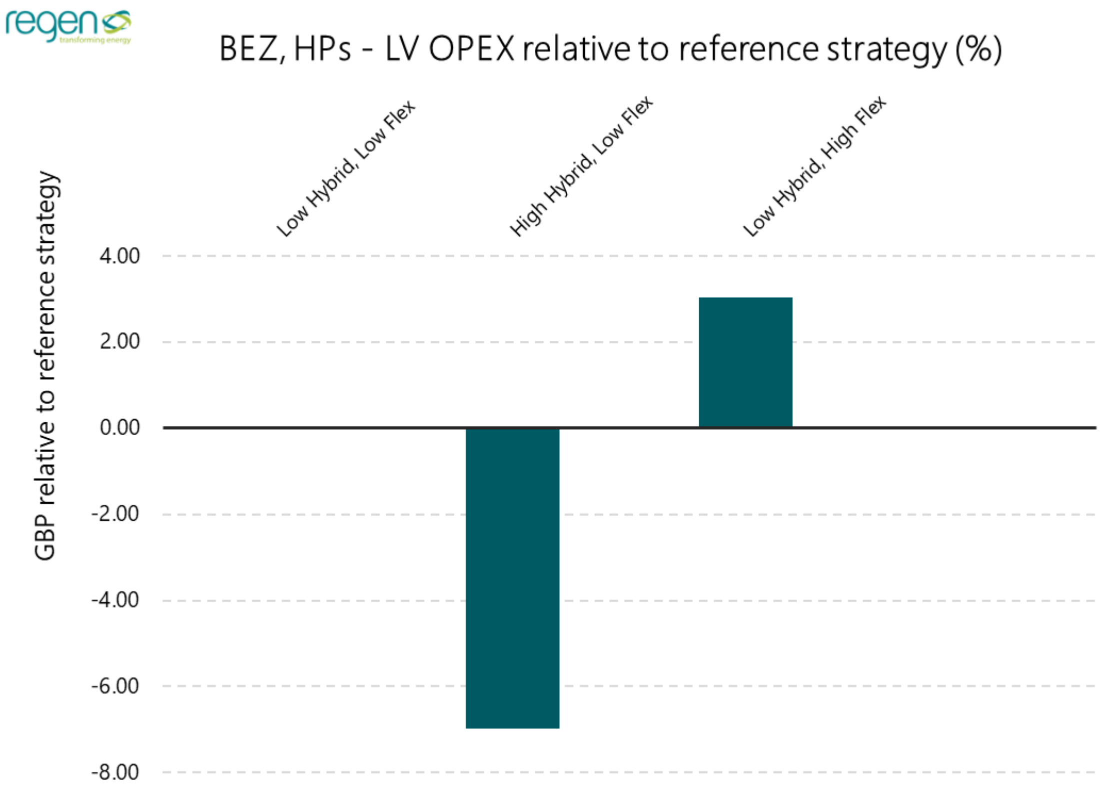


*Figure 14: Total LV OPEX by 2050 on the Dorchester St Primary*

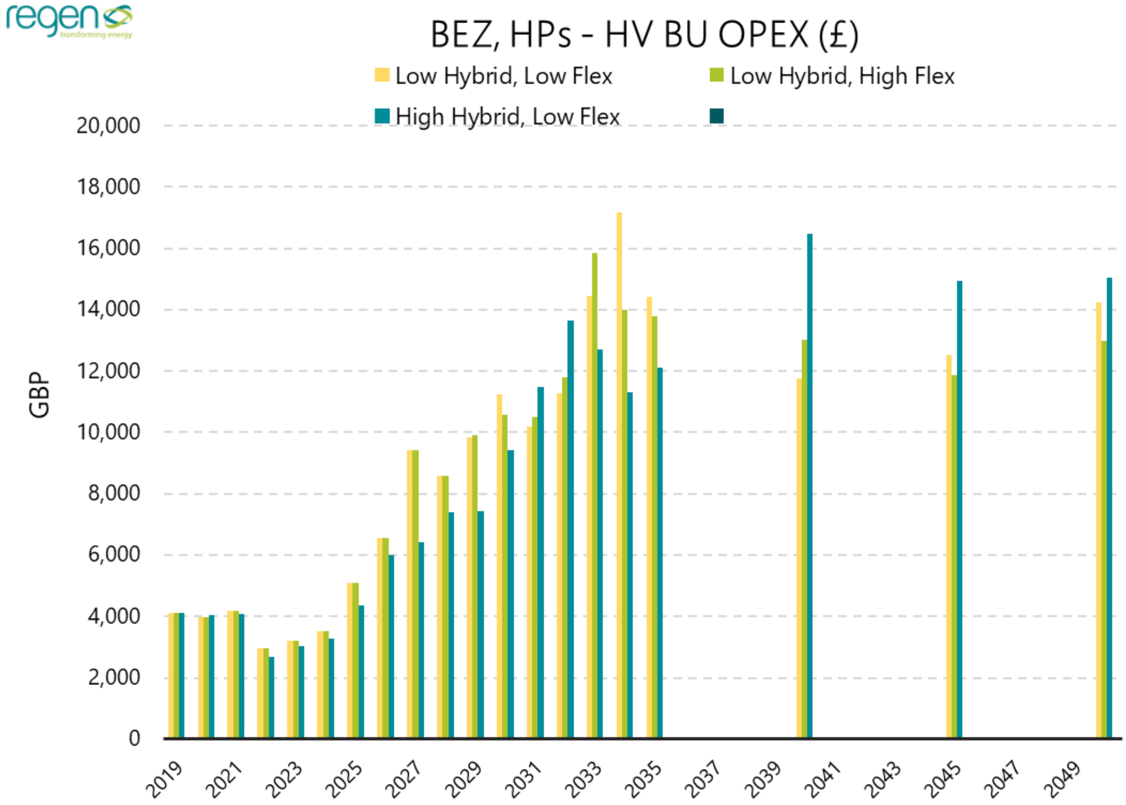


*Figure 15: HV OPEX by year on the Dorchester St Primary, from bottom up analysis*

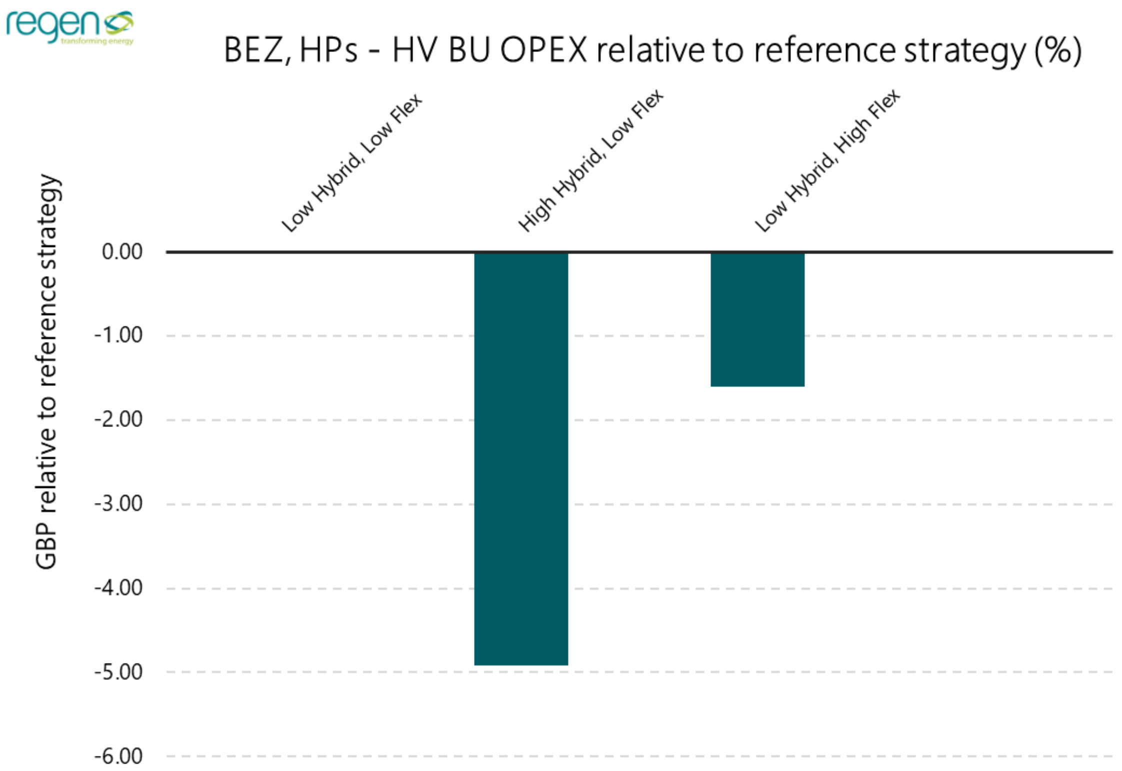


*Figure 16: Total HV OPEX by 2050 on the Dorchester St Primary, from bottom up analysis*

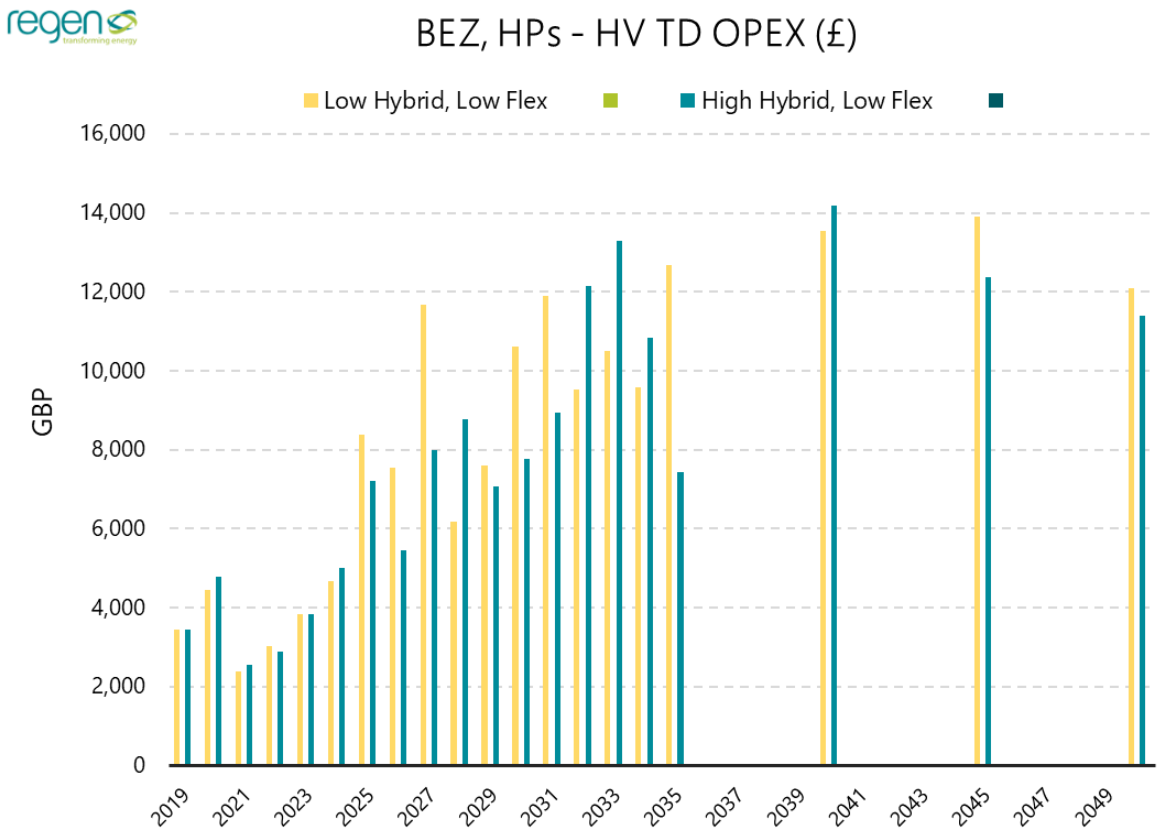


*Figure 17: HV OPEX by year on the Dorchester St Primary, from top down analaysis*

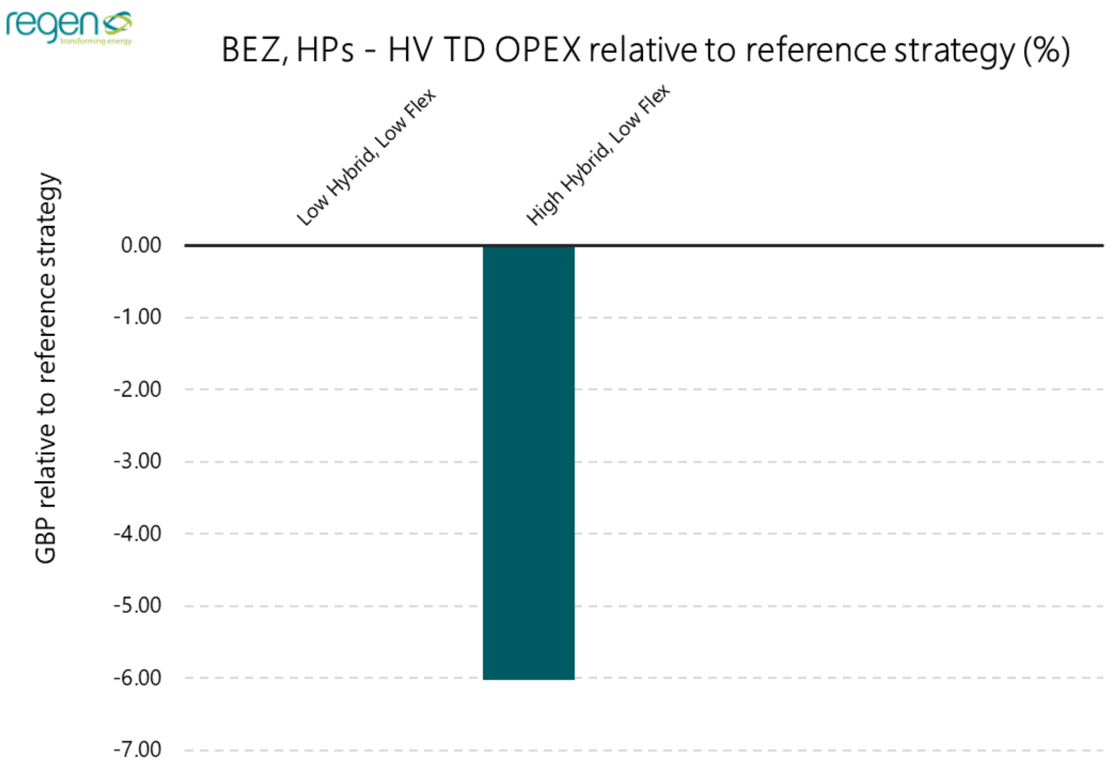


*Figure 18: Total HV OPEX by 2050 on the Dorchester St Primary, from top down analaysis*

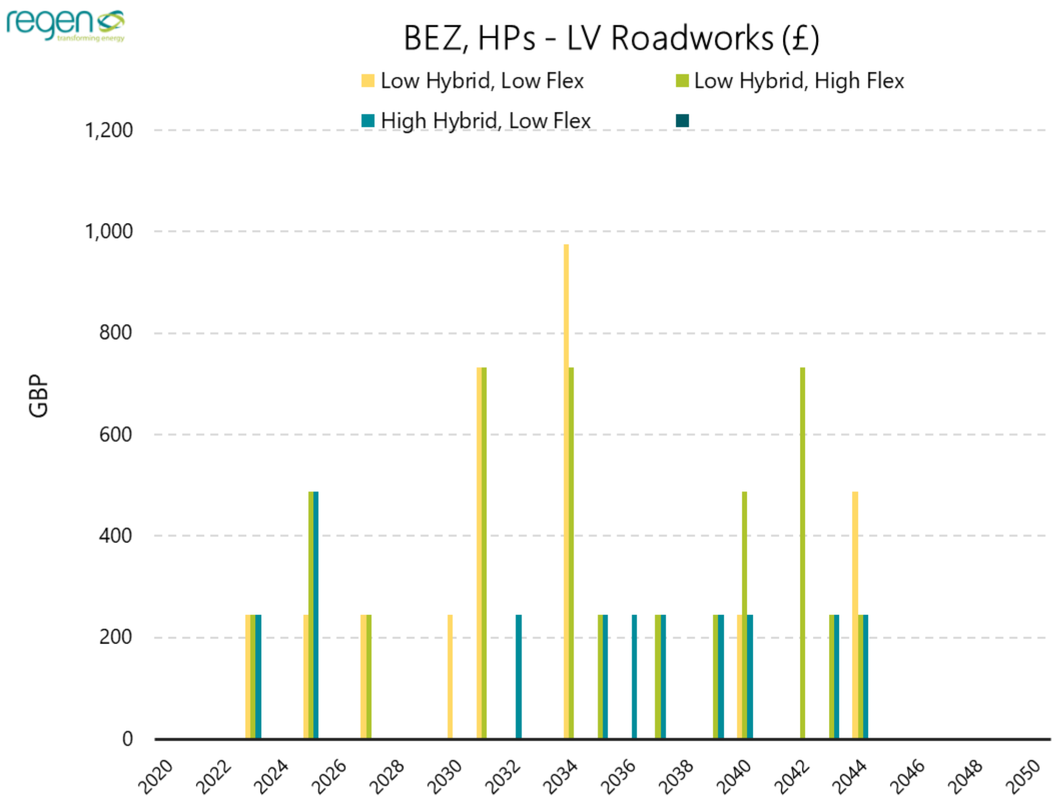


*Figure 19: LV roadworks by year on the Dorchester St Primary*

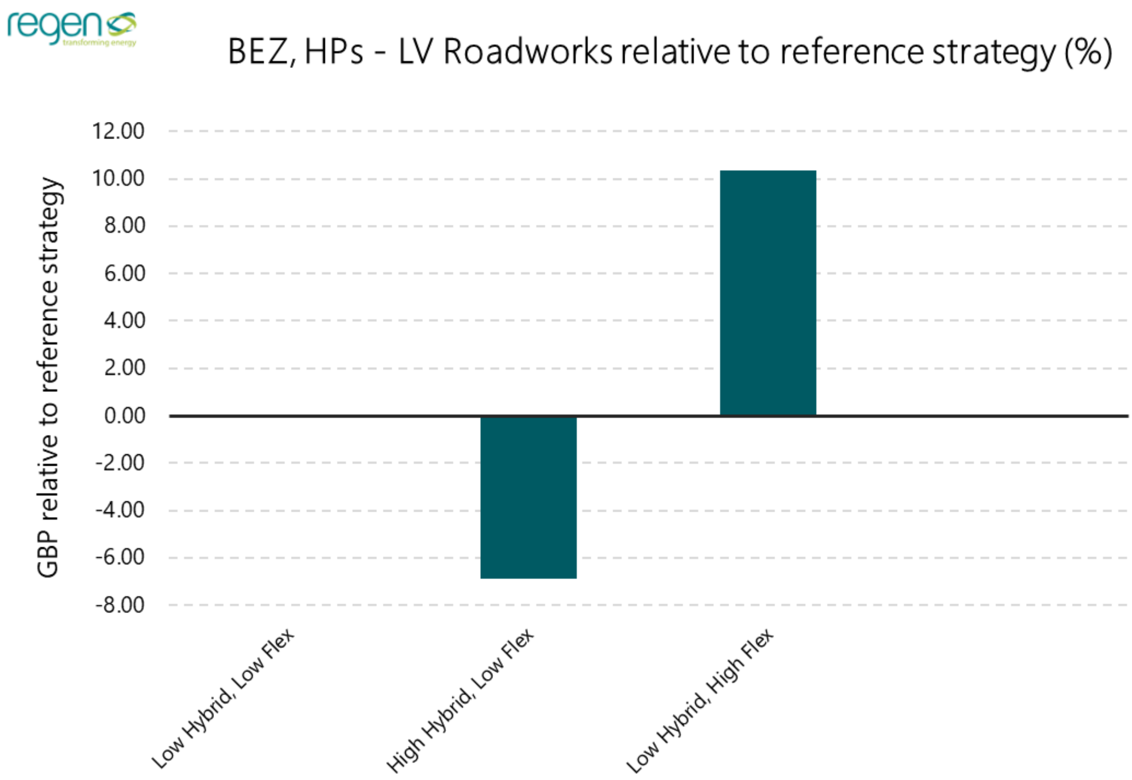


*Figure 20: Total LV roadworks by 2050 on the Dorchester St Primary*

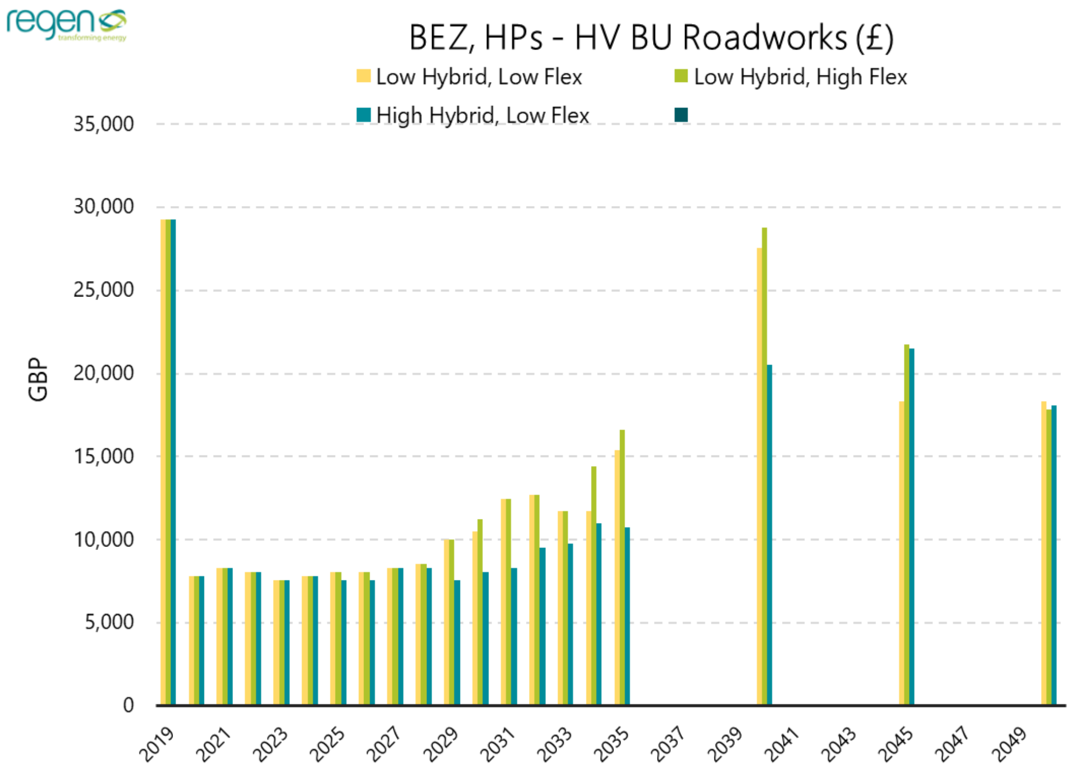


*Figure 21: HV roadworks by year on the Dorchester St Primary, from bottom up analysis*

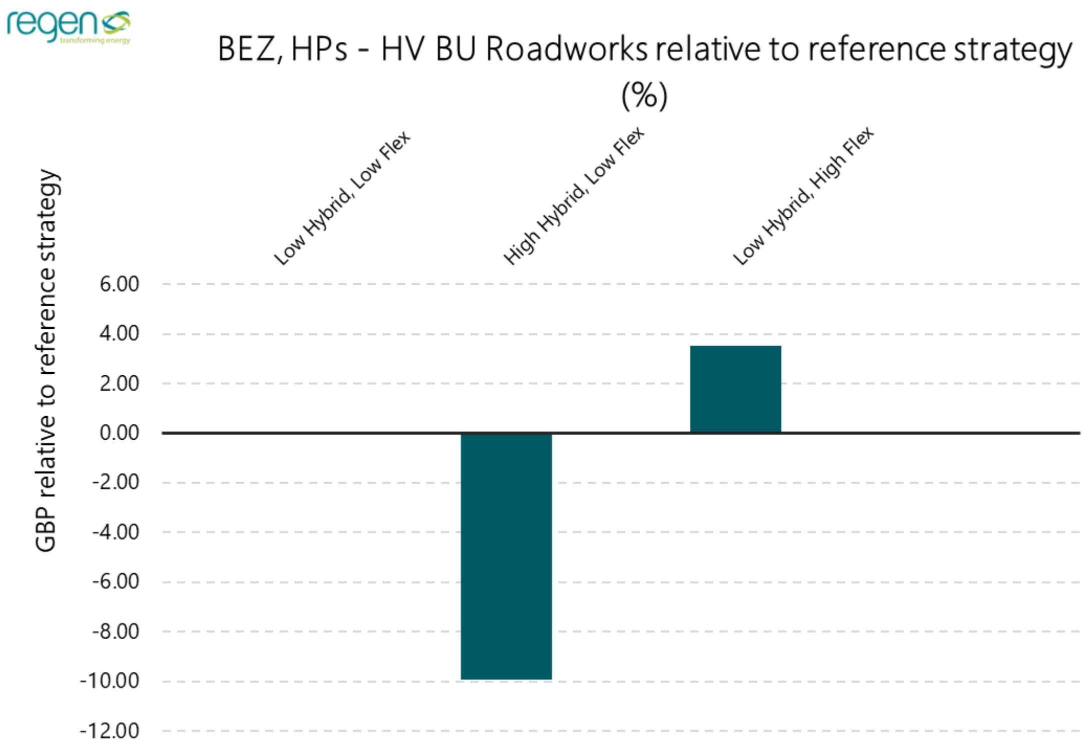


*Figure 22: Total HV roadworks by 2050 on the Dorchester St Primary, from bottom up analysis*

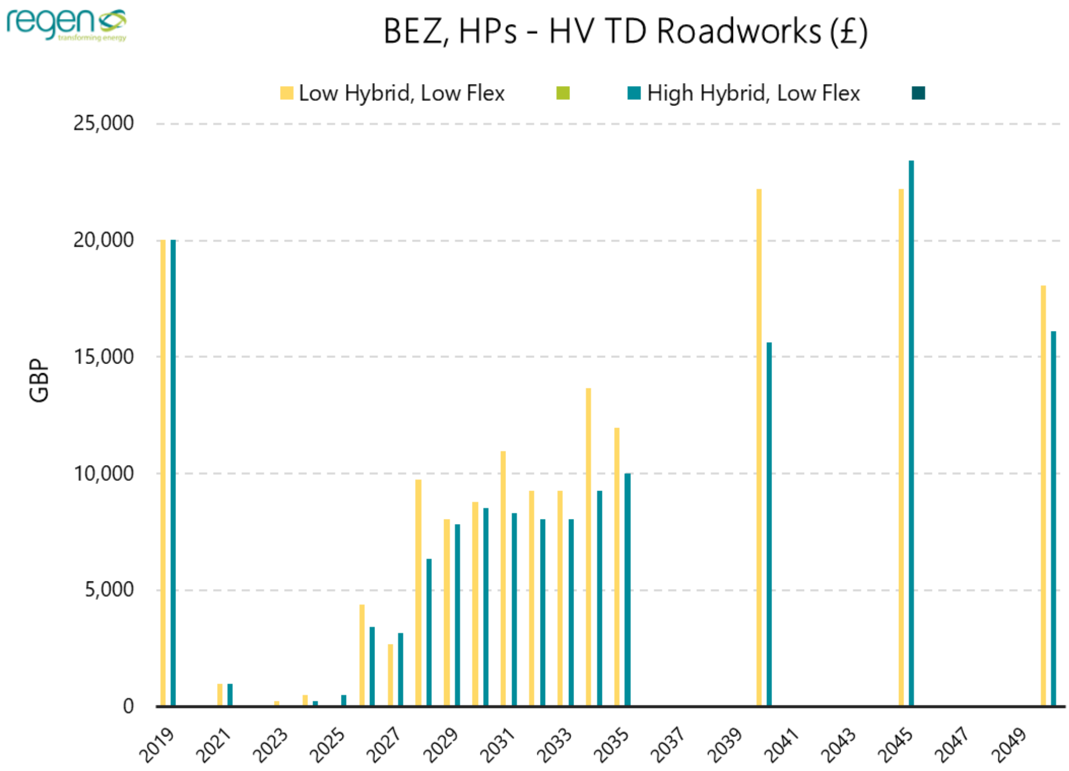


*Figure 23: HV roadworks by year on the Dorchester St Primary, from top down analaysis*

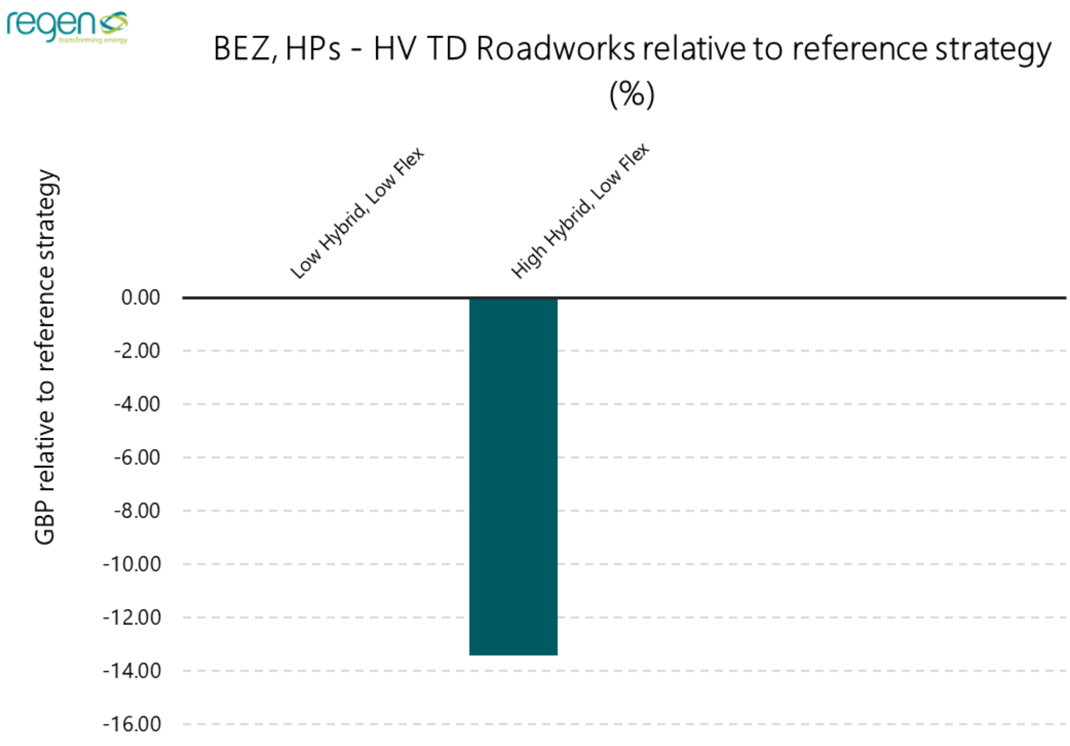


*Figure 24: Total HV roadworks by 2050 on the Dorchester St Primary, from top down analaysis*

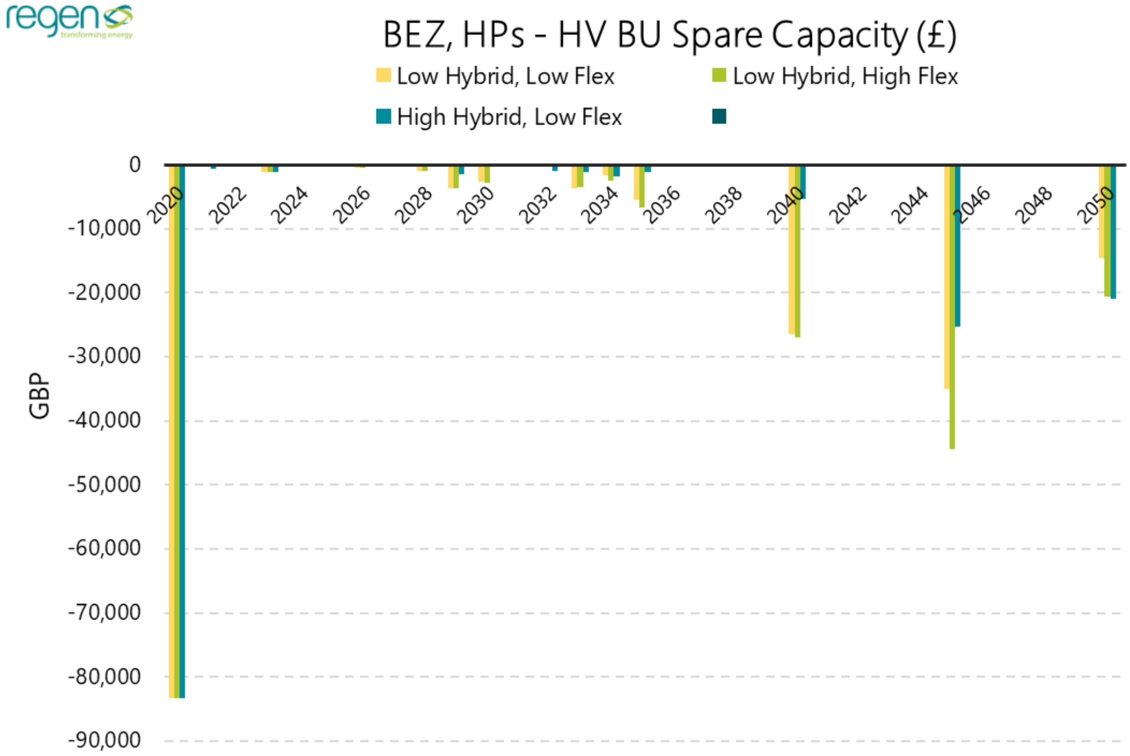


*Figure 25: HV Spare Capacity by year on the Dorchester St Primary, from bottom up analysis*

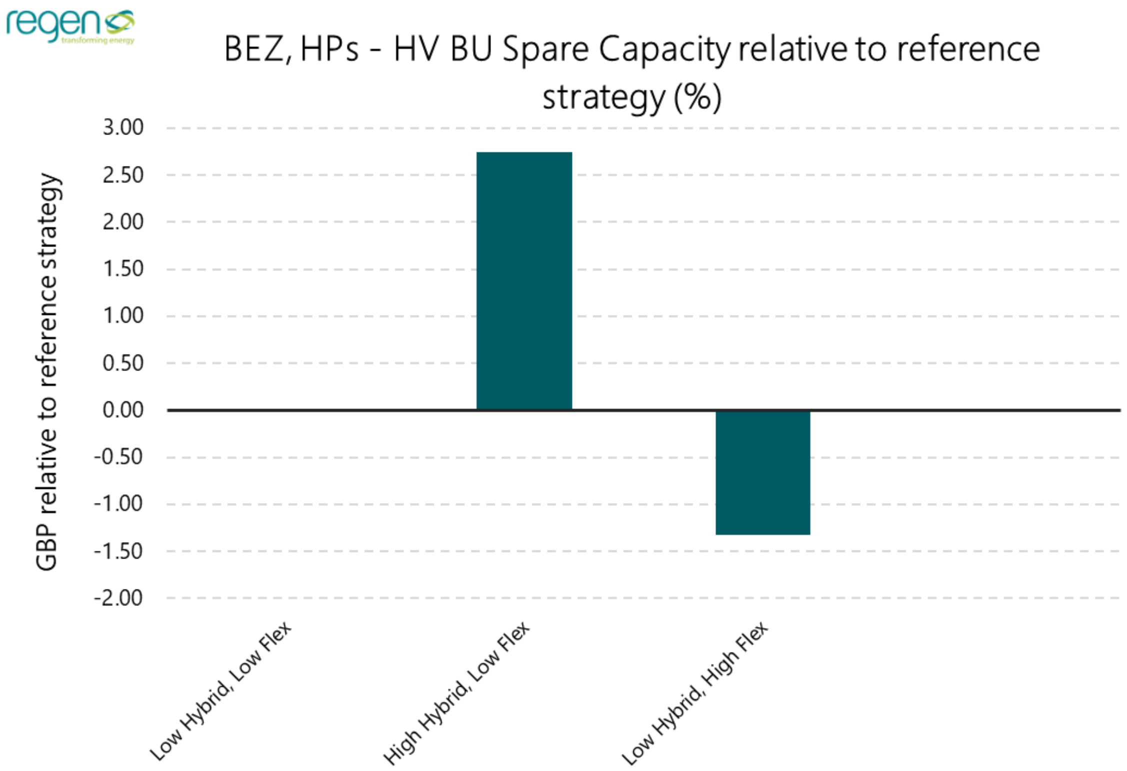


*Figure 26: Total HV Spare Capacity by 2050 on the Dorchester St Primary, from bottom up analysis*

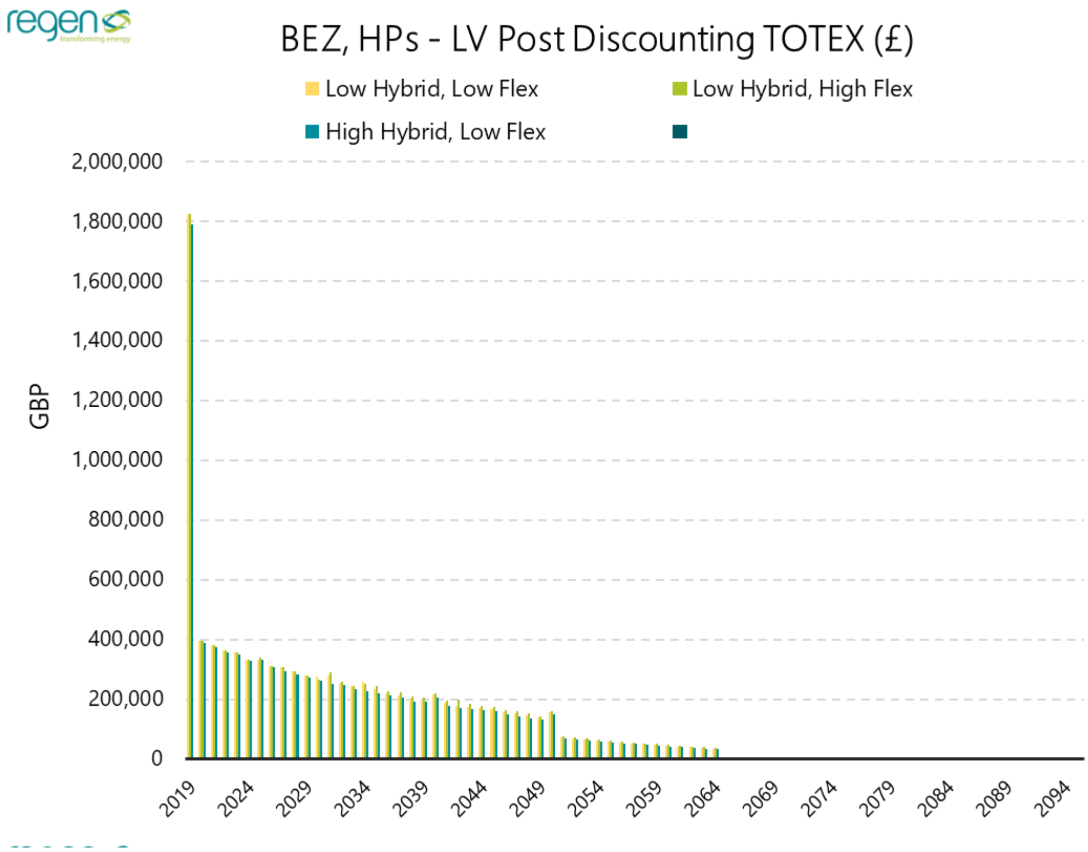


*Figure 27: Post Discounting LV TOTEX by year on the Dorchester St Primary*

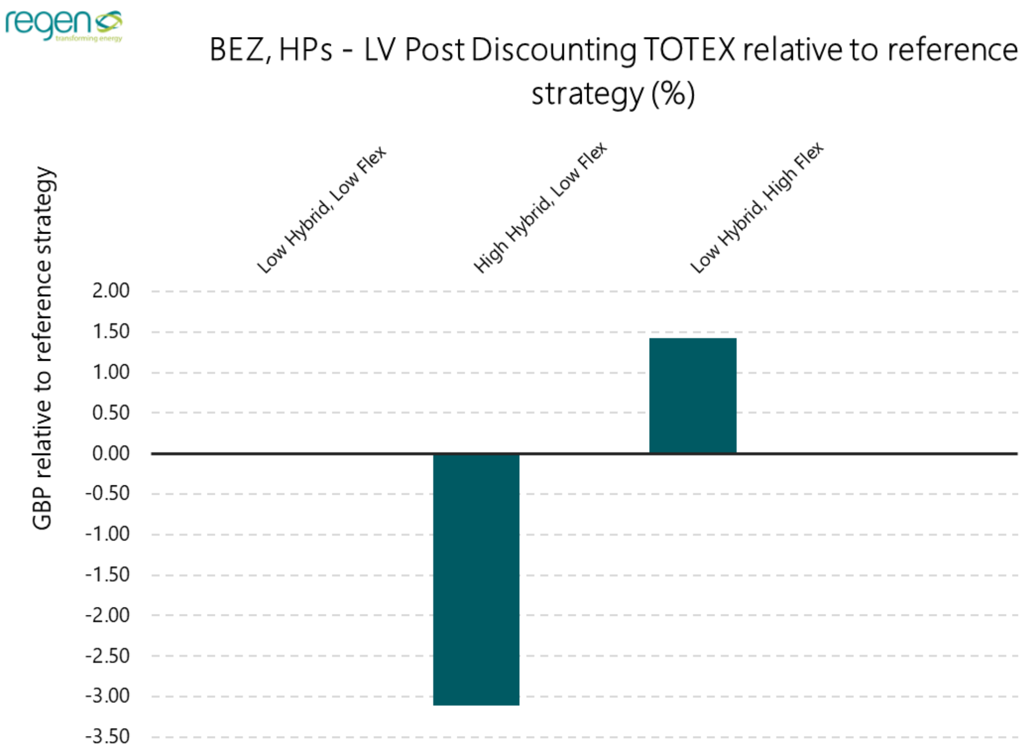


*Figure 28: Total Post Discounting LV TOTEX by 2050 on the Dorchester St Primary*

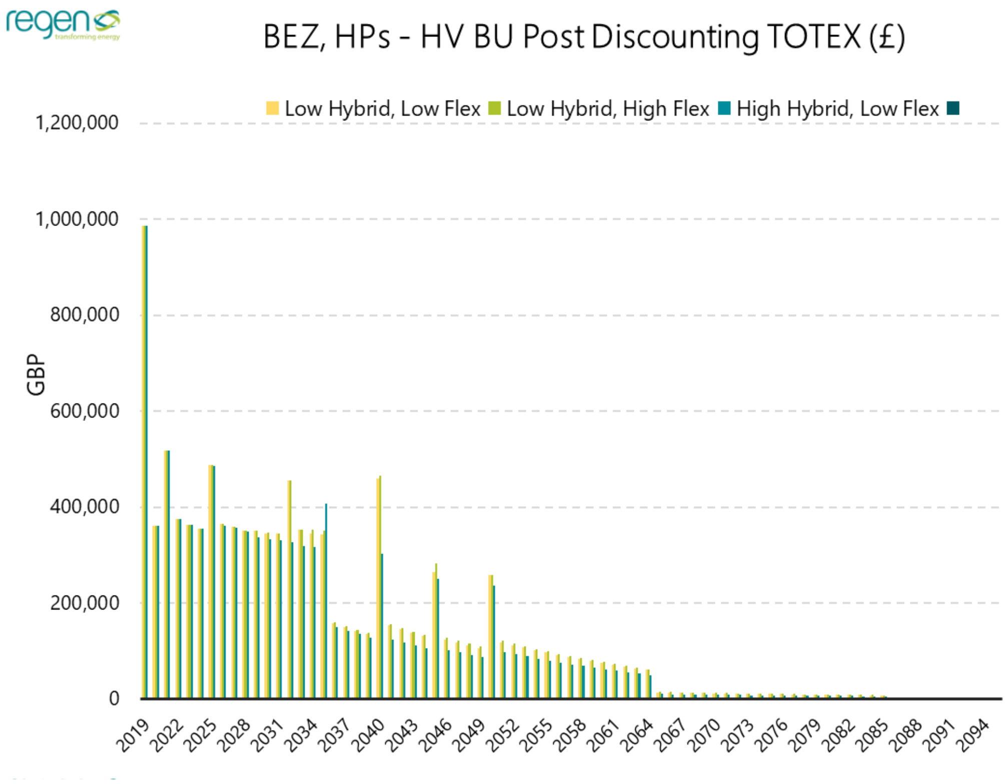


*Figure 29: Post Discounting HV TOTEX by year on the Dorchester St Primary, from bottom up analysis*

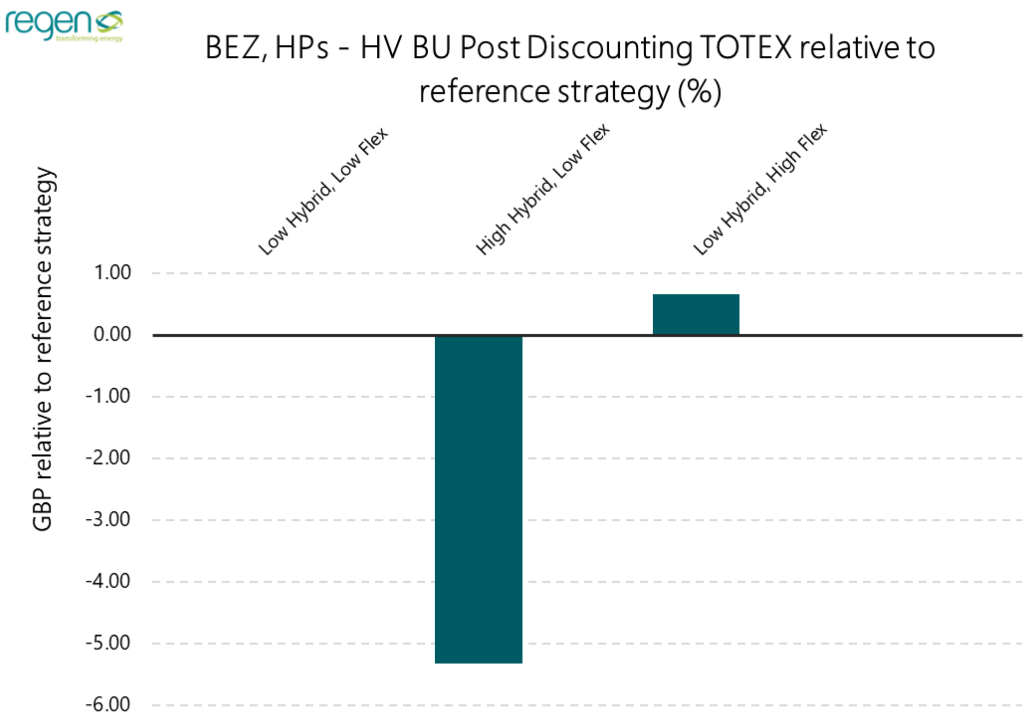


*Figure 30: Total Post Discounting HV TOTEX by 2050 on the Dorchester St Primary, from bottom up analysis*

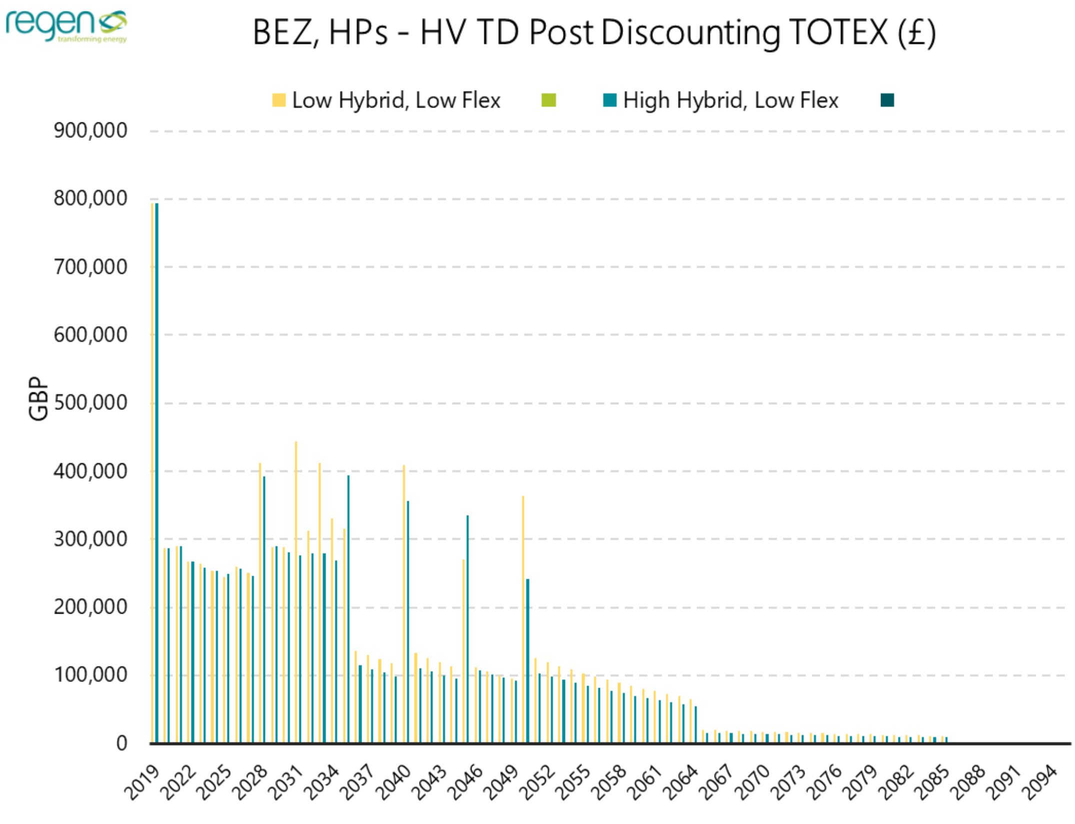


*Figure 31: Post Discounting HV TOTEX by year on the Dorchester St Primary, from top down analaysis*

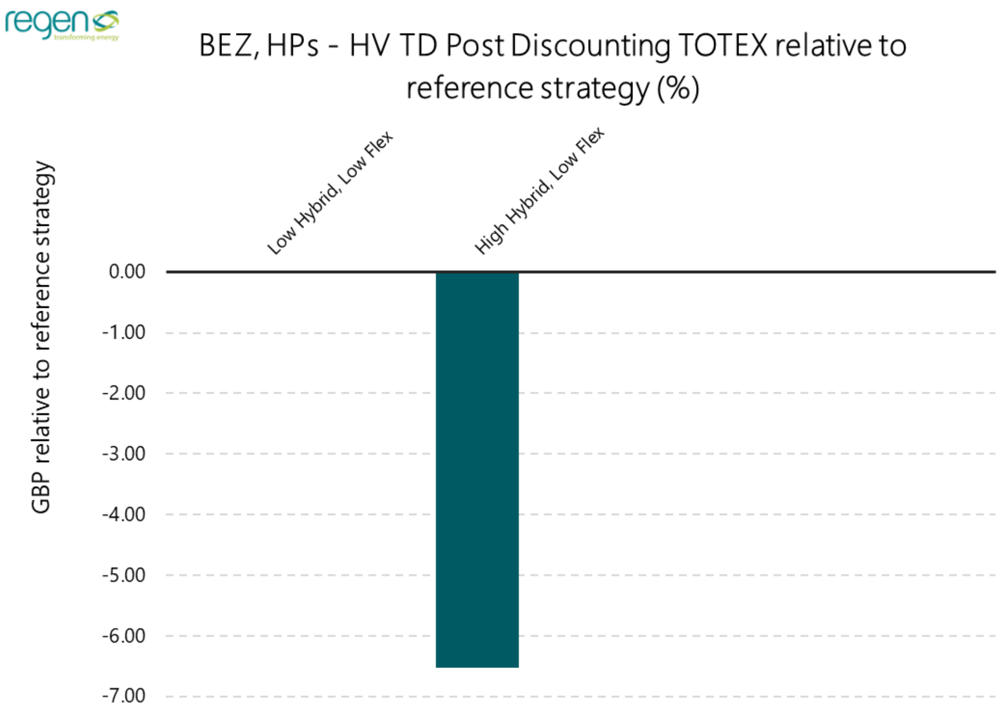


*Figure 32: Total Post Discounting HV TOTEX by 2050 on the Dorchester St Primary, from top down analaysis*

# 7. APPENDIX 2: Cribbs Causeway significant results

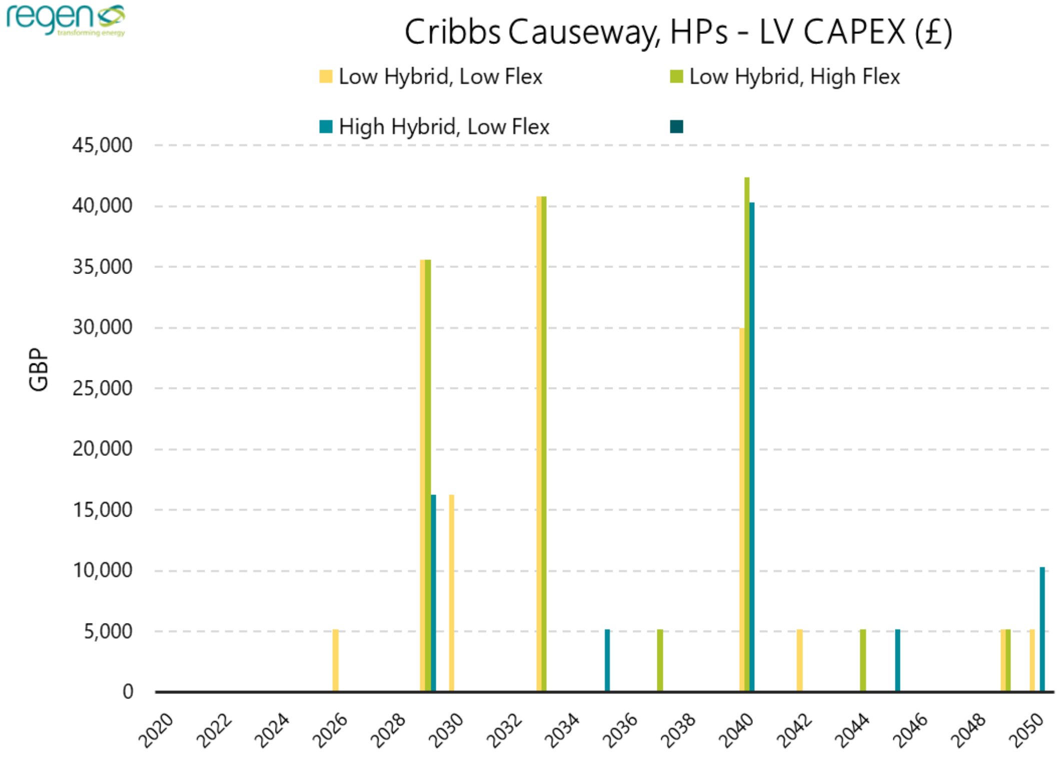


*Figure 33 LV CAPEX by year on the Cribbs Causeway primary*

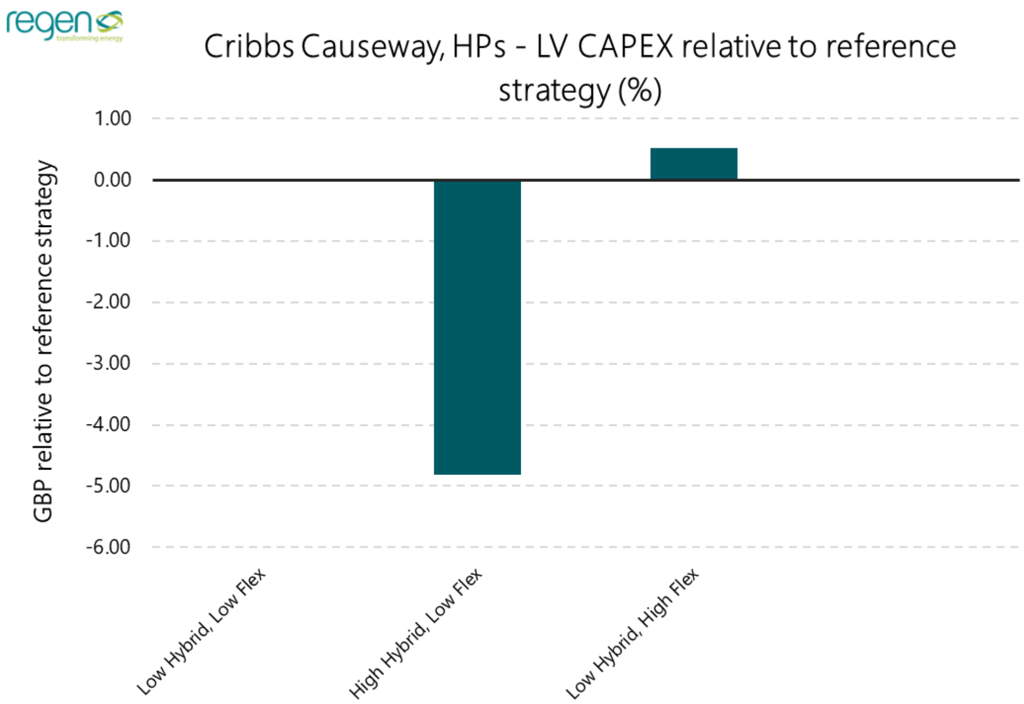


*Figure 34: Total LV CAPEX by 2050 on the Cribbs Causeway primary*

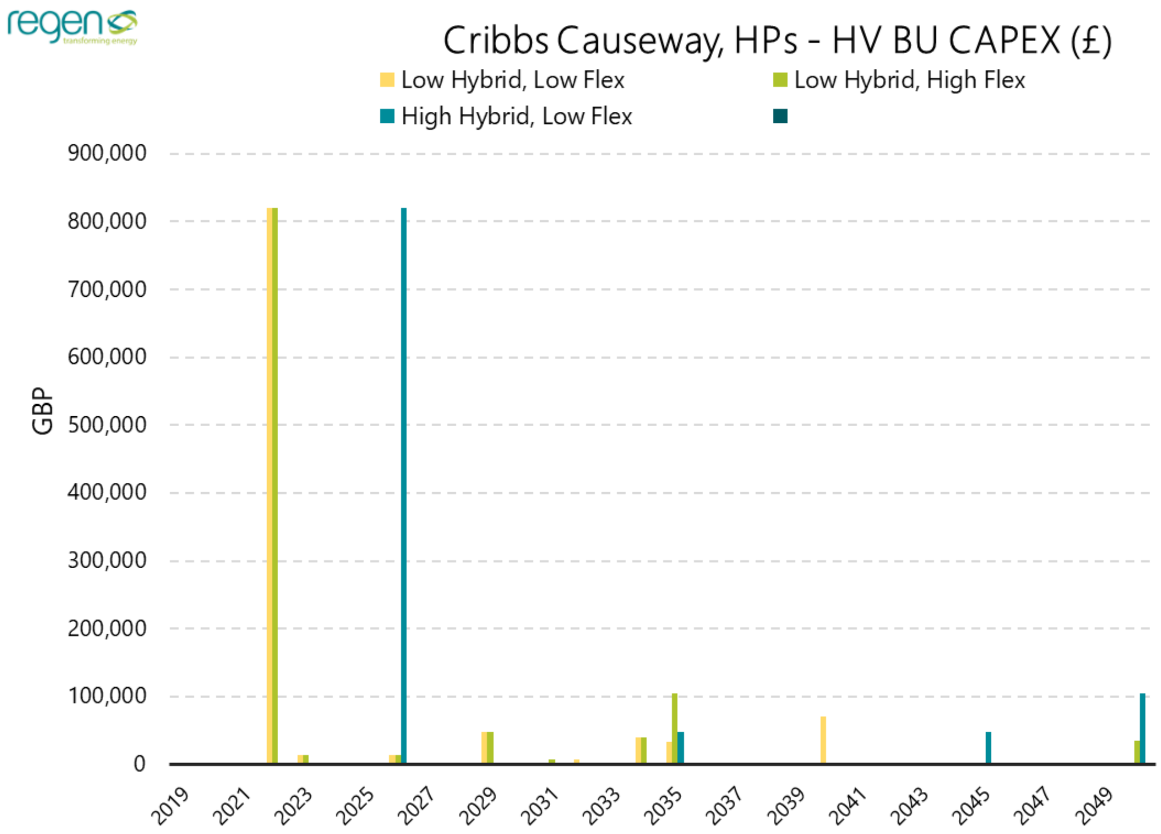


*Figure 35: HV CAPEX by year on the Cribbs Causeway primary, from bottom up analysis*

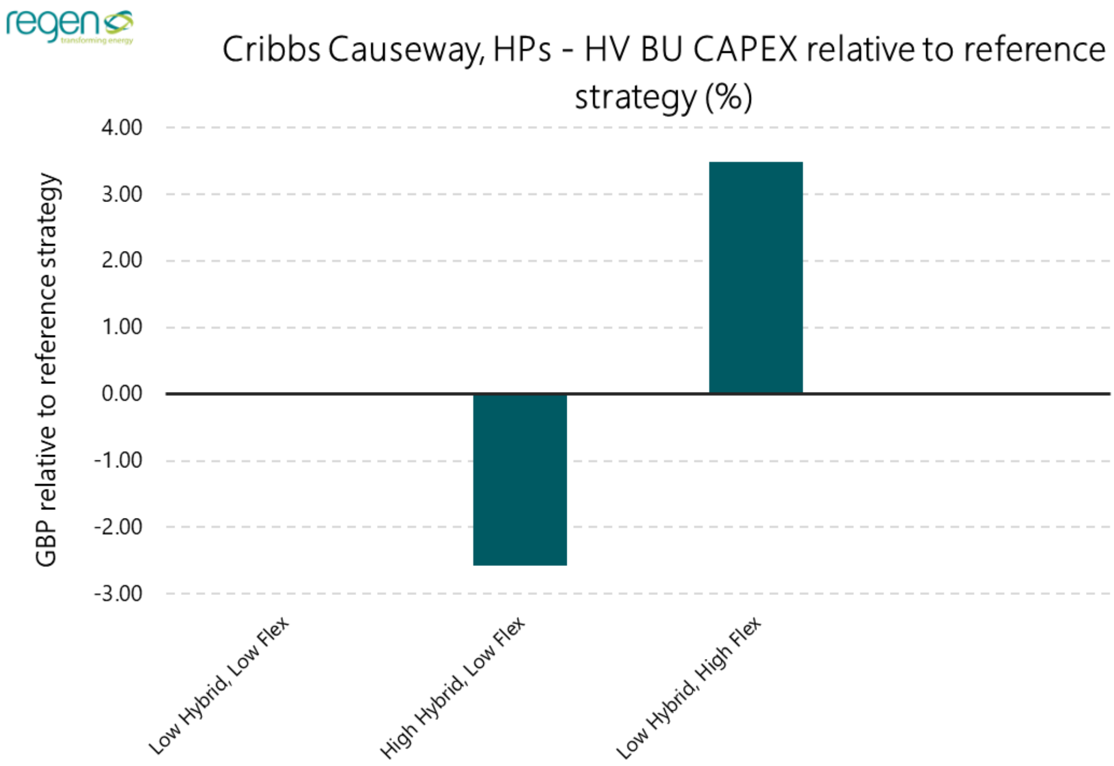


*Figure 36: Total HV CAPEX by 2050 on the Cribbs Causeway primary, from bottom up analysis*

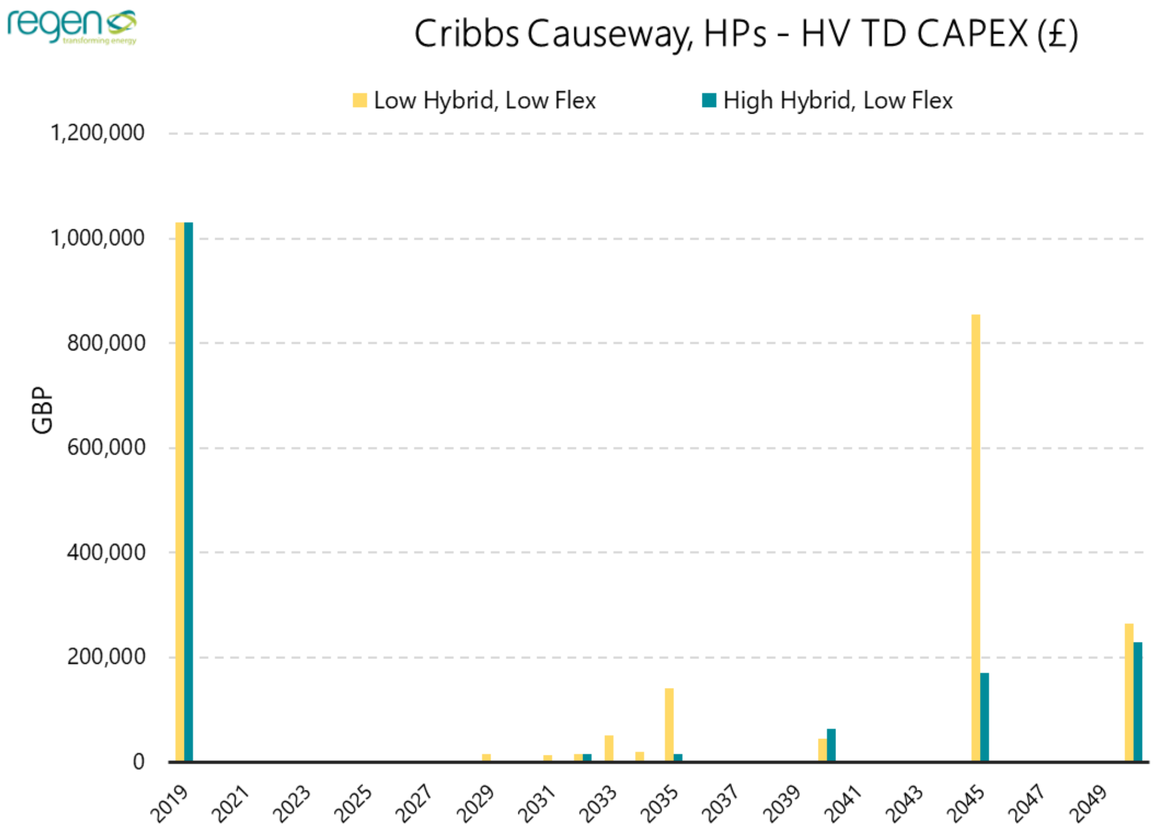


*Figure 37: HV CAPEX by year on the Cribbs Causeway primary, from top down analaysis*

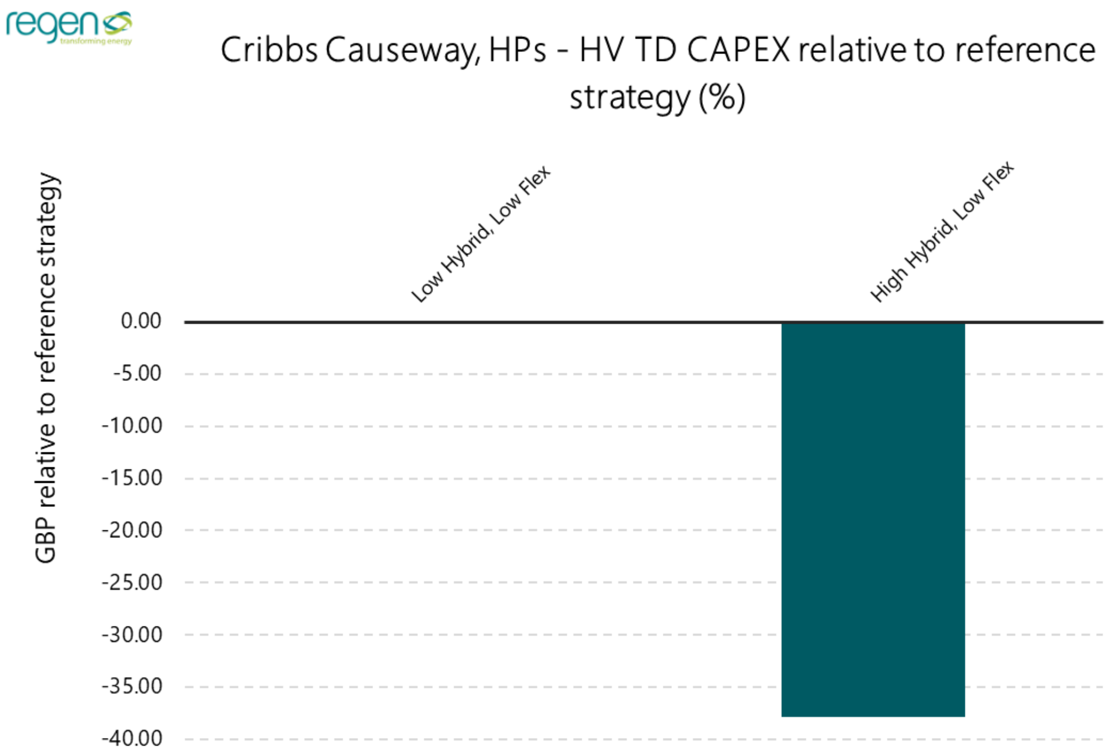


*Figure 38: Total HV CAPEX by 2050 on the Cribbs Causeway primary, from top down analaysis*

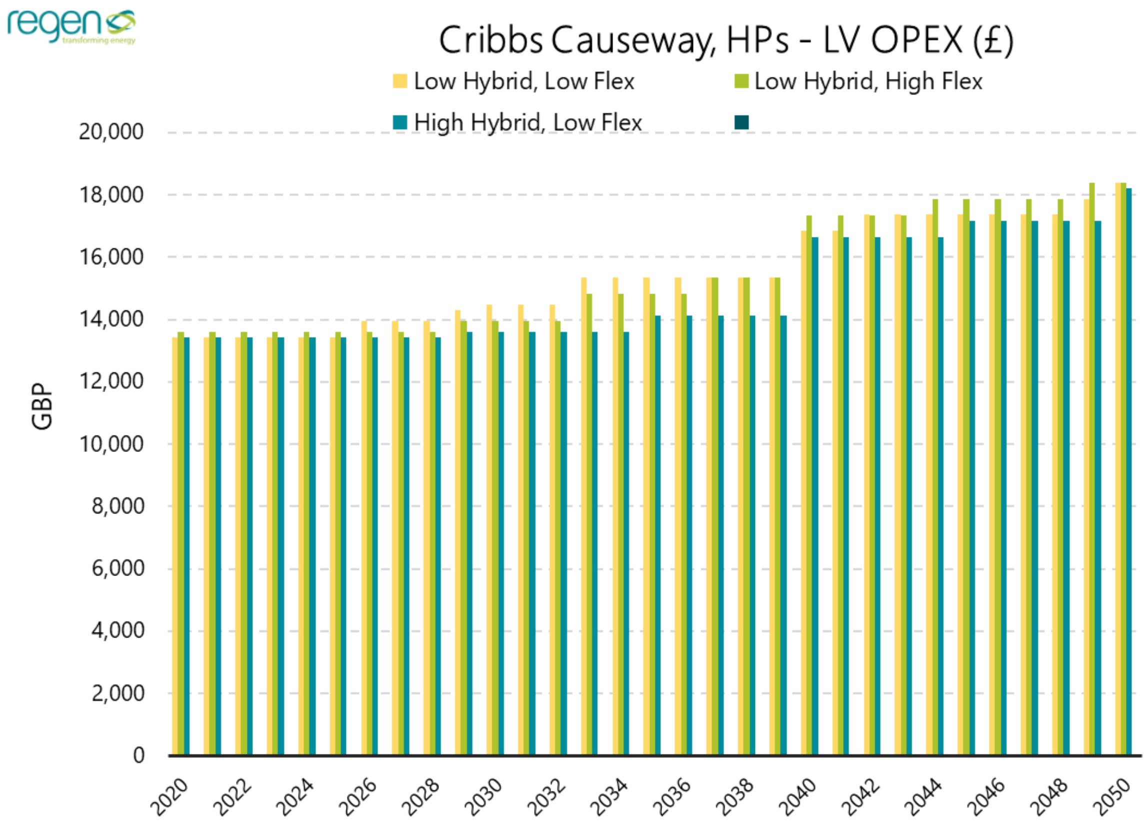


*Figure 39: LV OPEX by year on the Cribbs Causeway primary*

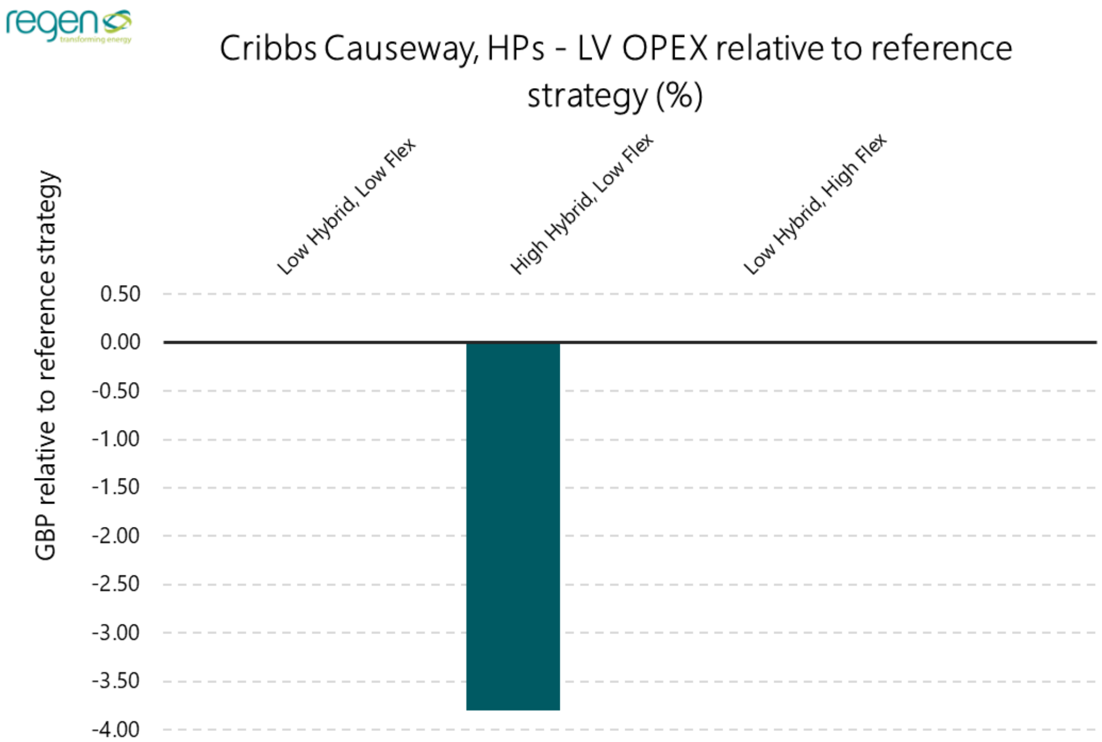


*Figure 40: Total LV OPEX by 2050 on the Cribbs Causeway primary*

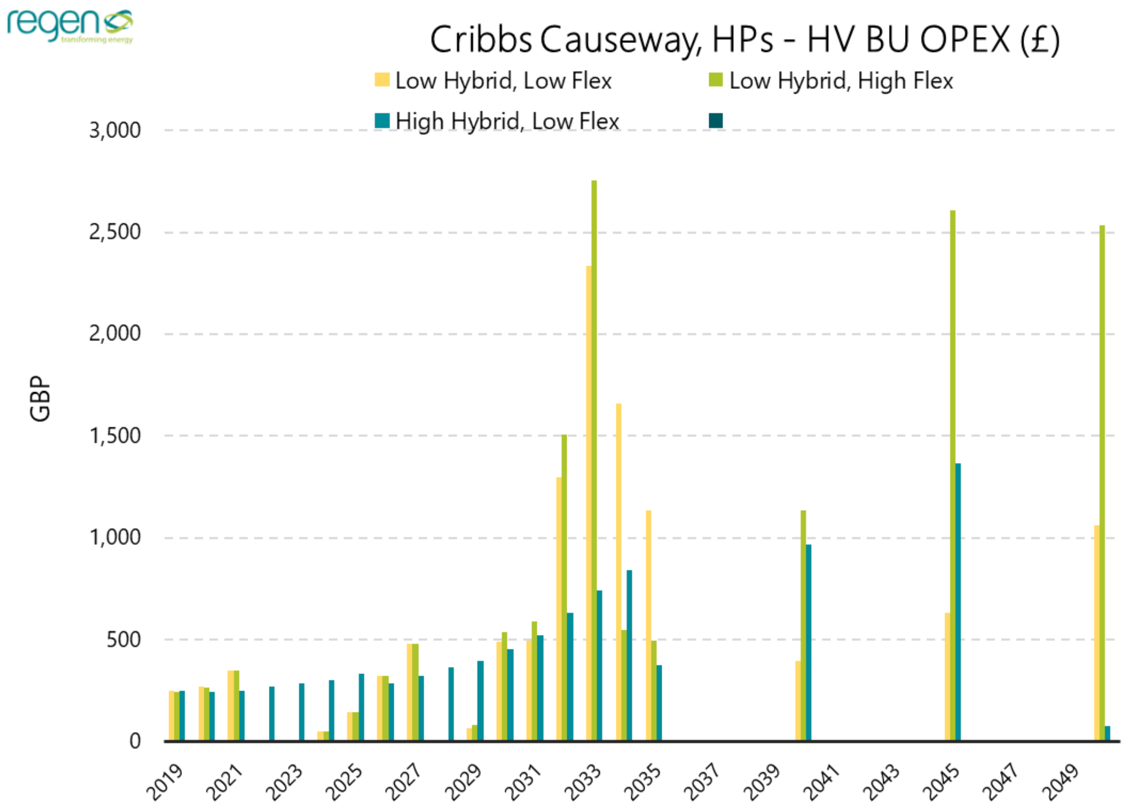


*Figure 41: HV OPEX by year on the Cribbs Causeway primary, from bottom up analysis*

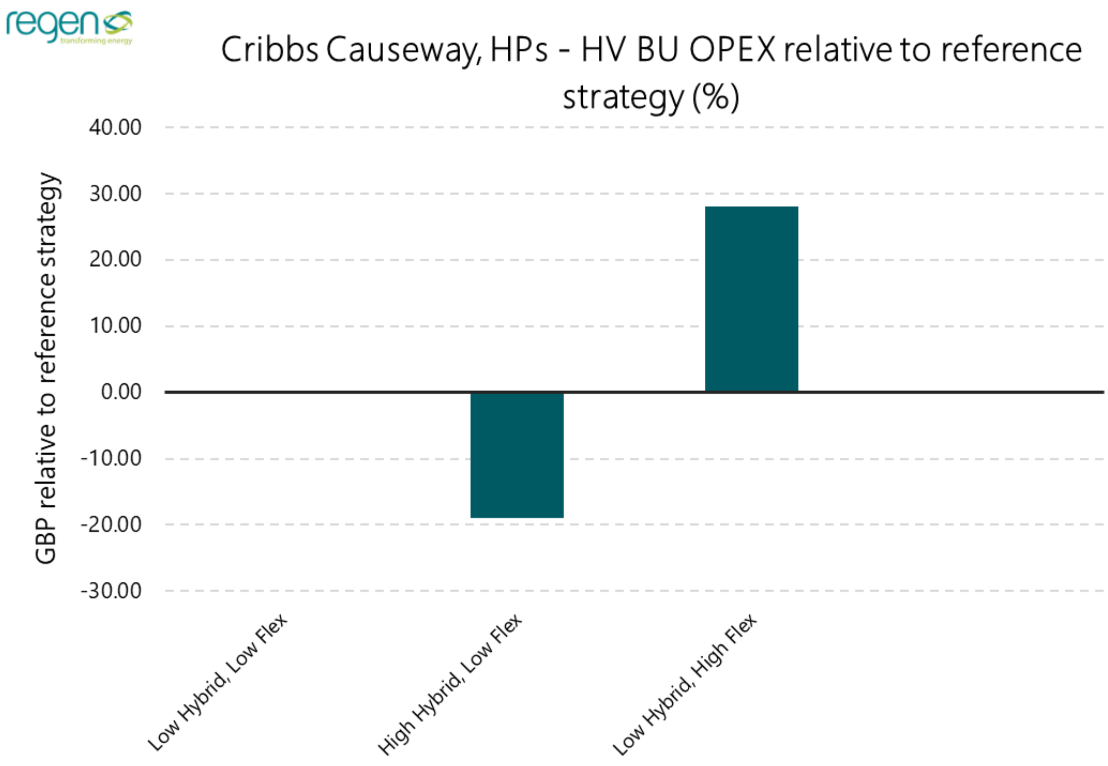


*Figure 42: Total HV OPEX by 2050 on the Cribbs Causeway primary, from bottom up analysis*

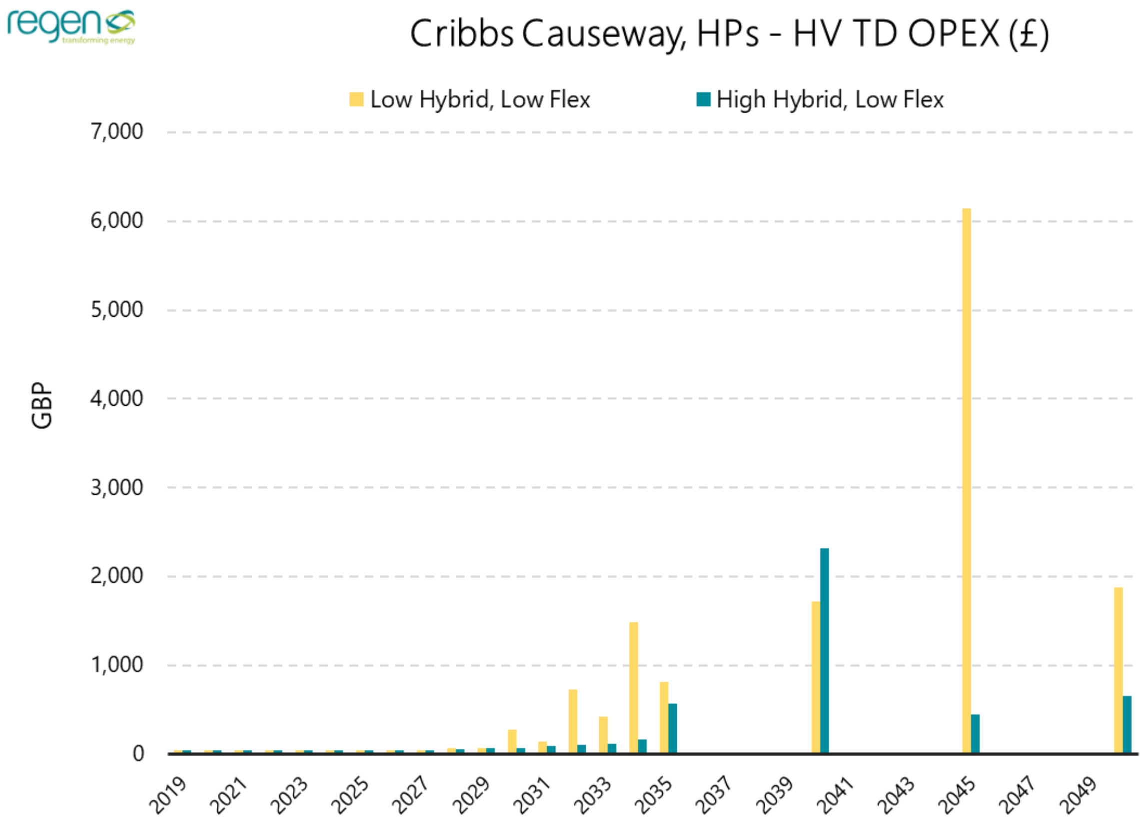


*Figure 43: HV OPEX by year on the Cribbs Causeway primary, from top down analaysis*

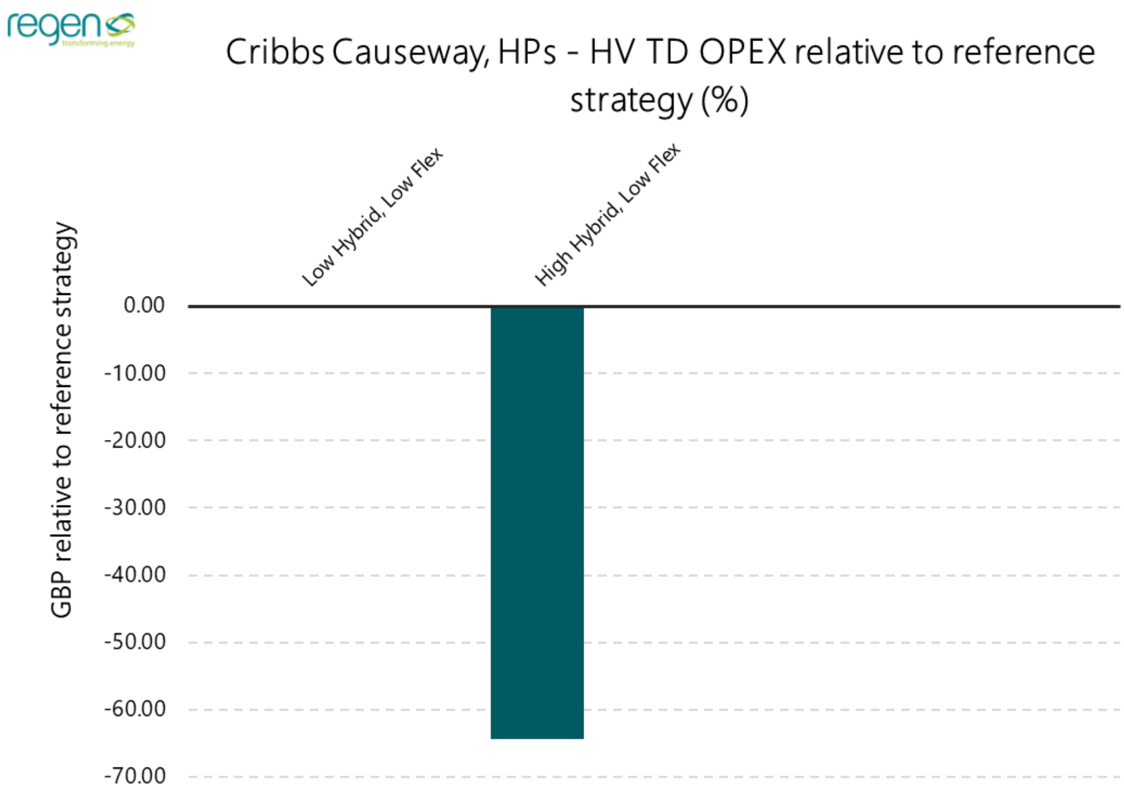


*Figure 44: Total HV OPEX by 2050 on the Cribbs Causeway primary, from top down analaysis*

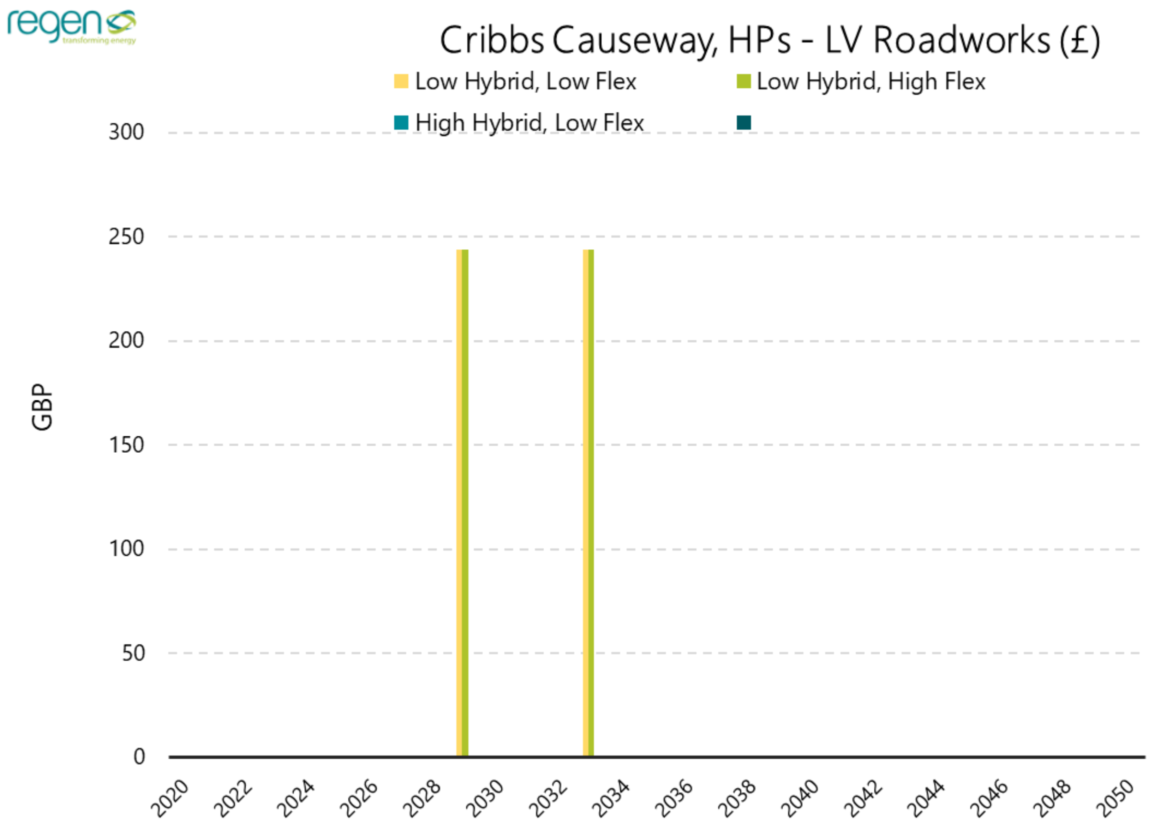


*Figure 45: LV roadworks by year on the Cribbs Causeway primary*

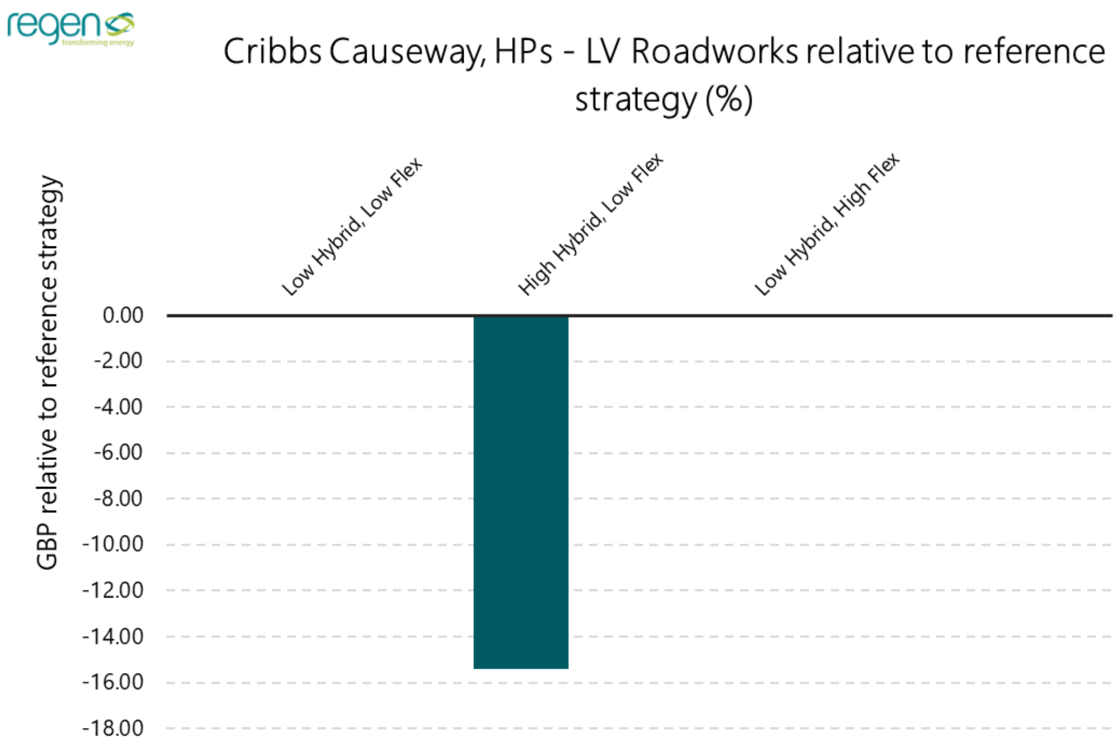


*Figure 46: Total LV roadworks by 2050 on the Cribbs Causeway primary*

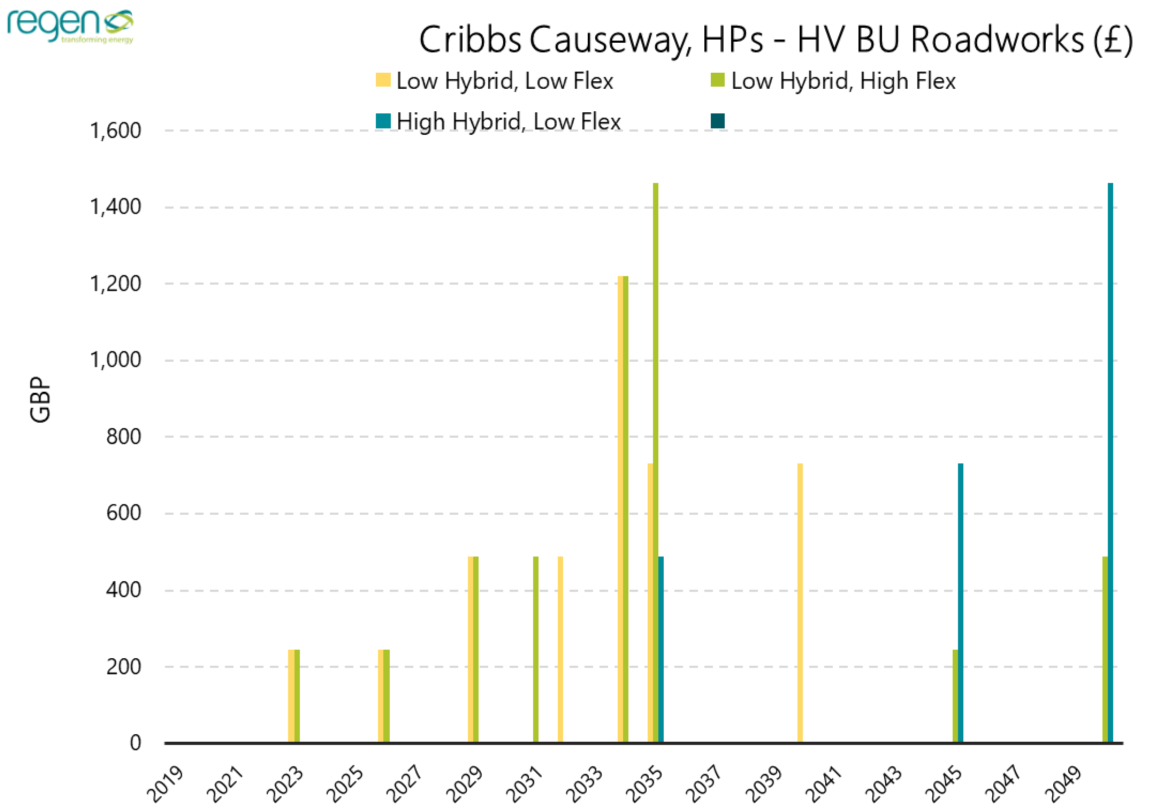


*Figure 47: HV roadworks by year on the Cribbs Causeway primary, from bottom up analysis*

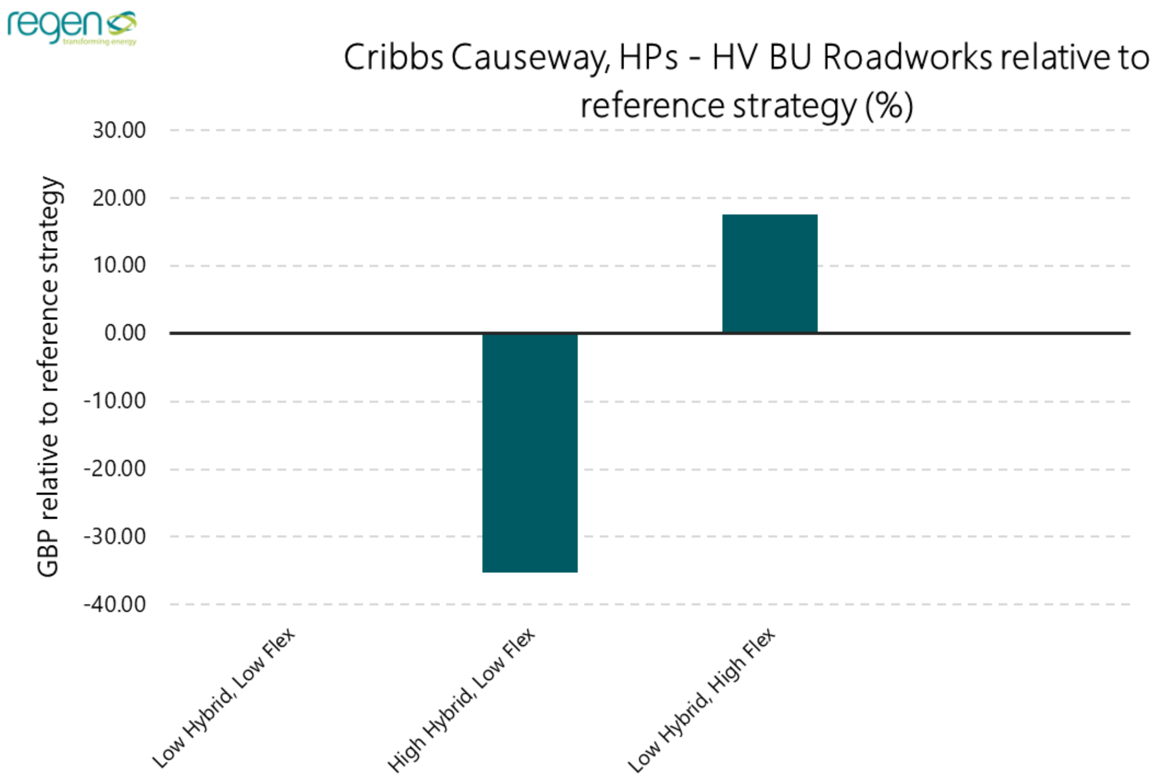


*Figure 48: Total HV roadworks by 2050 on the Cribbs Causeway primary, from bottom up analysis*

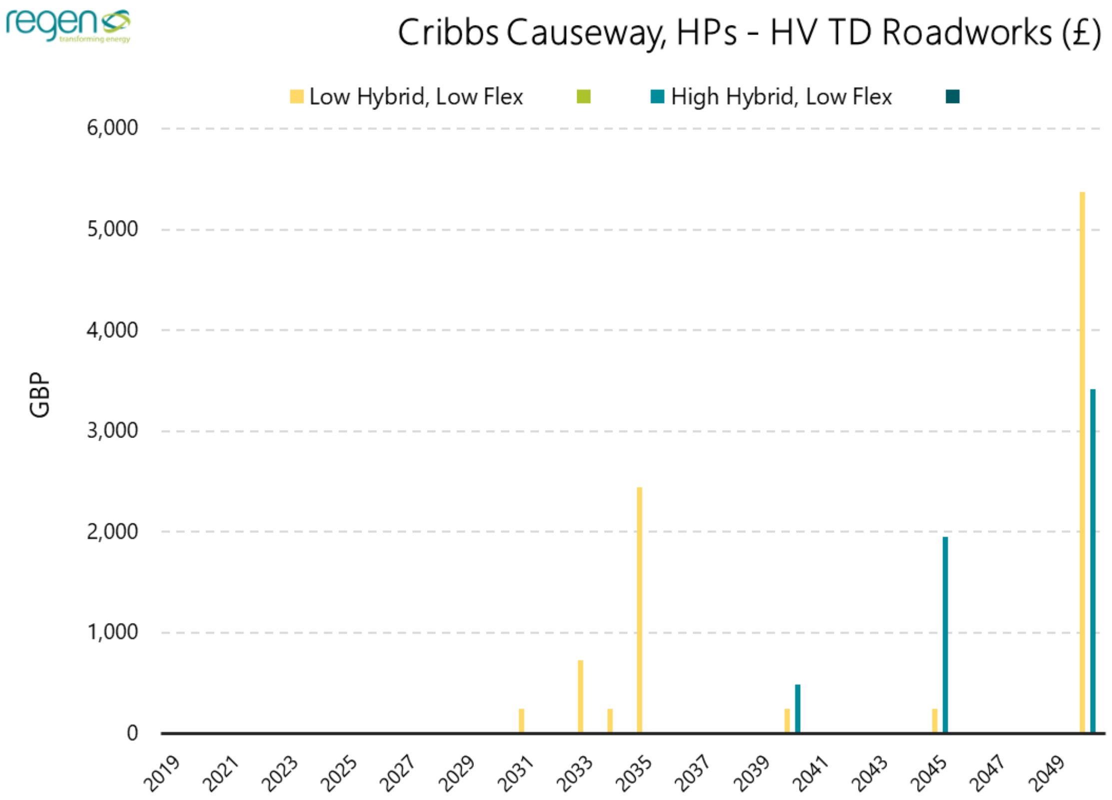


*Figure 49: HV roadworks by year on the Cribbs Causeway primary, from top down analaysis*

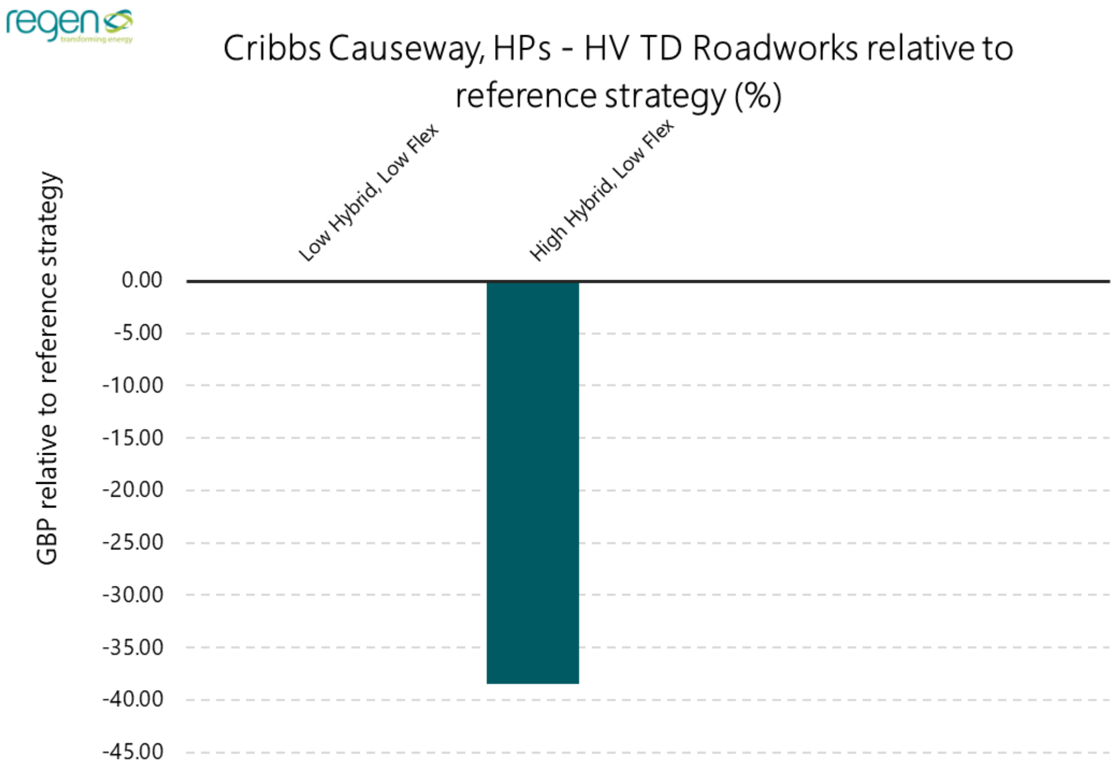


*Figure 50: Total HV roadworks by 2050 on the Cribbs Causeway primary, from top down analaysis*

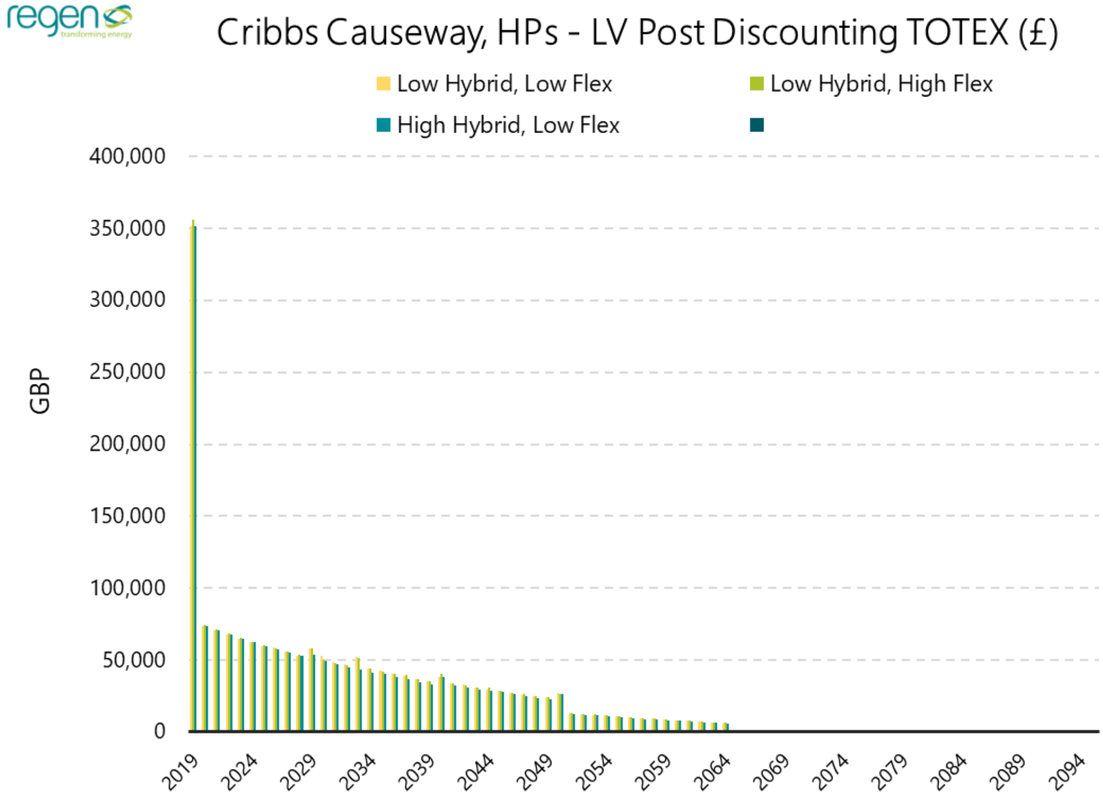


*Figure 51: Post Discounting LV TOTEX by year on the Cribbs Causeway primary*

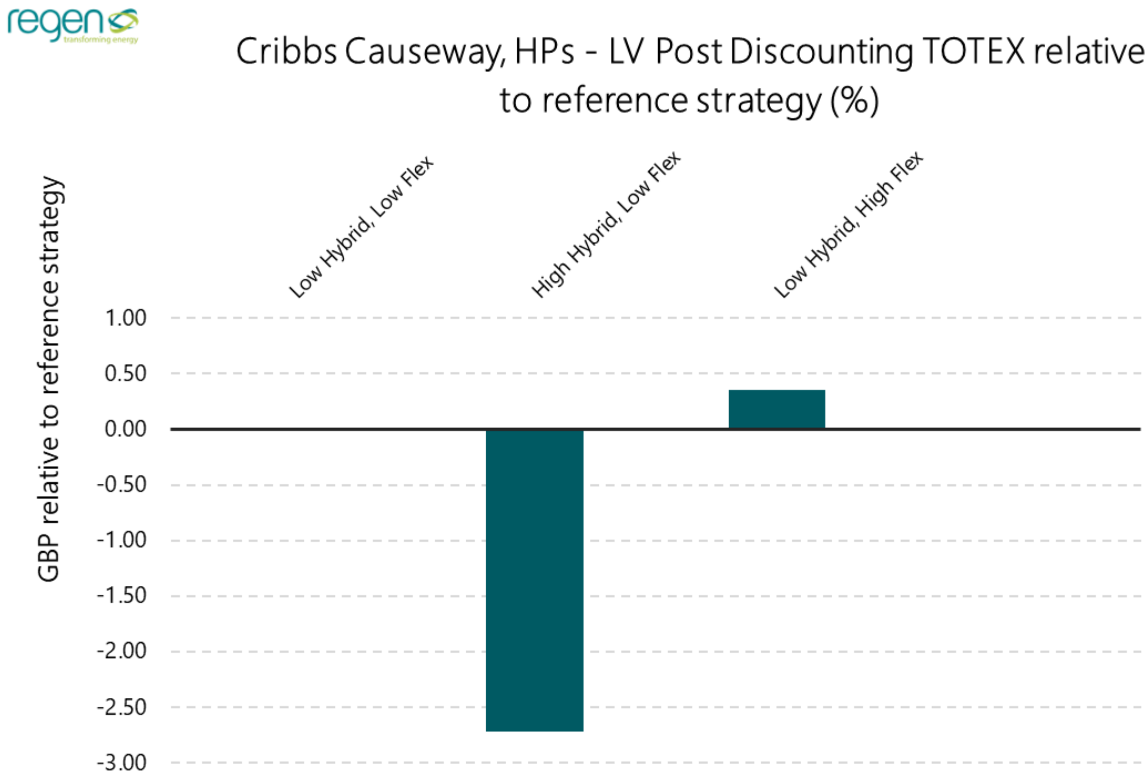


*Figure 52: Total Post Discounting LV TOTEX by 2050 on the Cribbs Causeway primary*

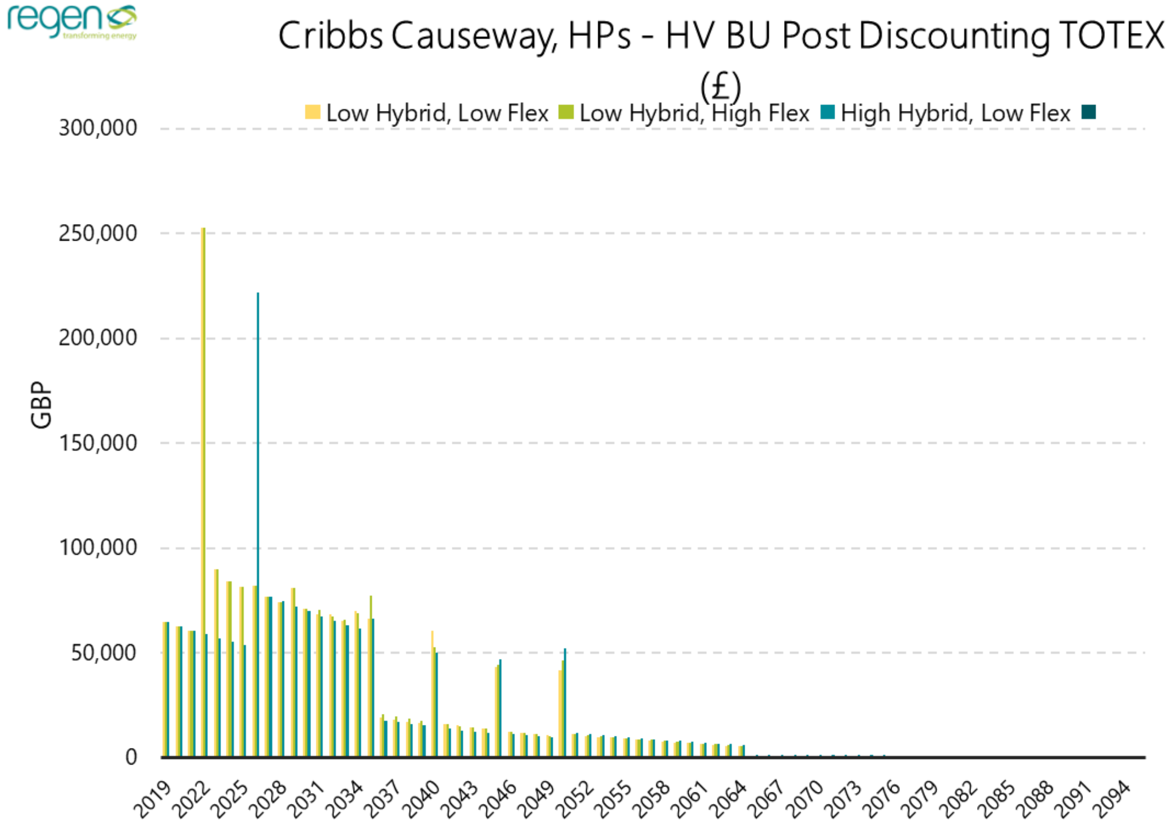


*Figure 53: Post Discounting HV TOTEX by year on the Cribbs Causeway primary, from bottom up analysis*

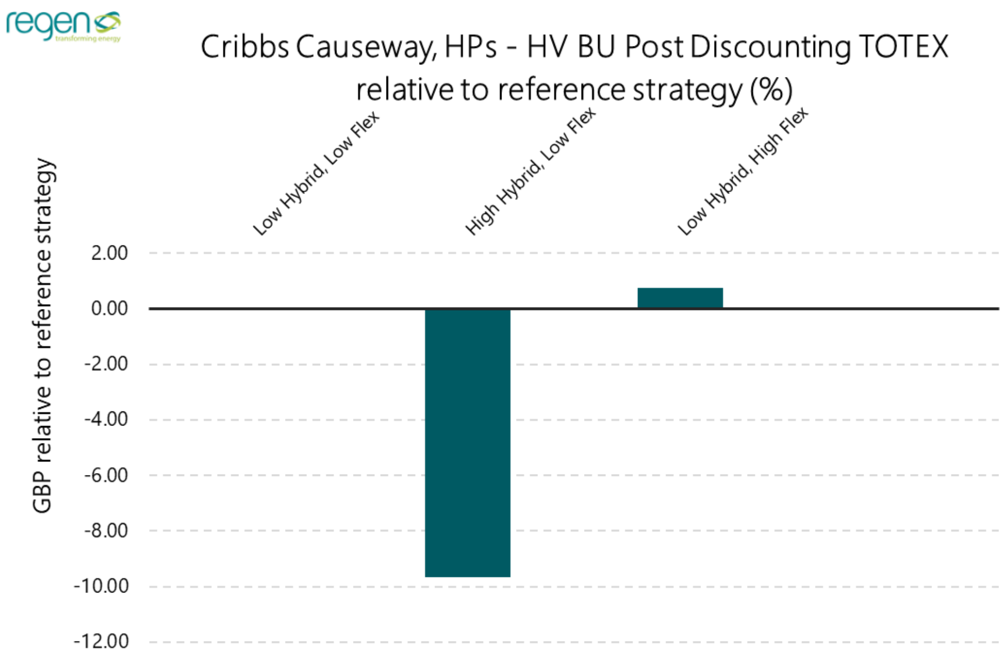


*Figure 54: Total Post Discounting HV TOTEX by 2050 on the Cribbs Causeway primary, from bottom up analysis*

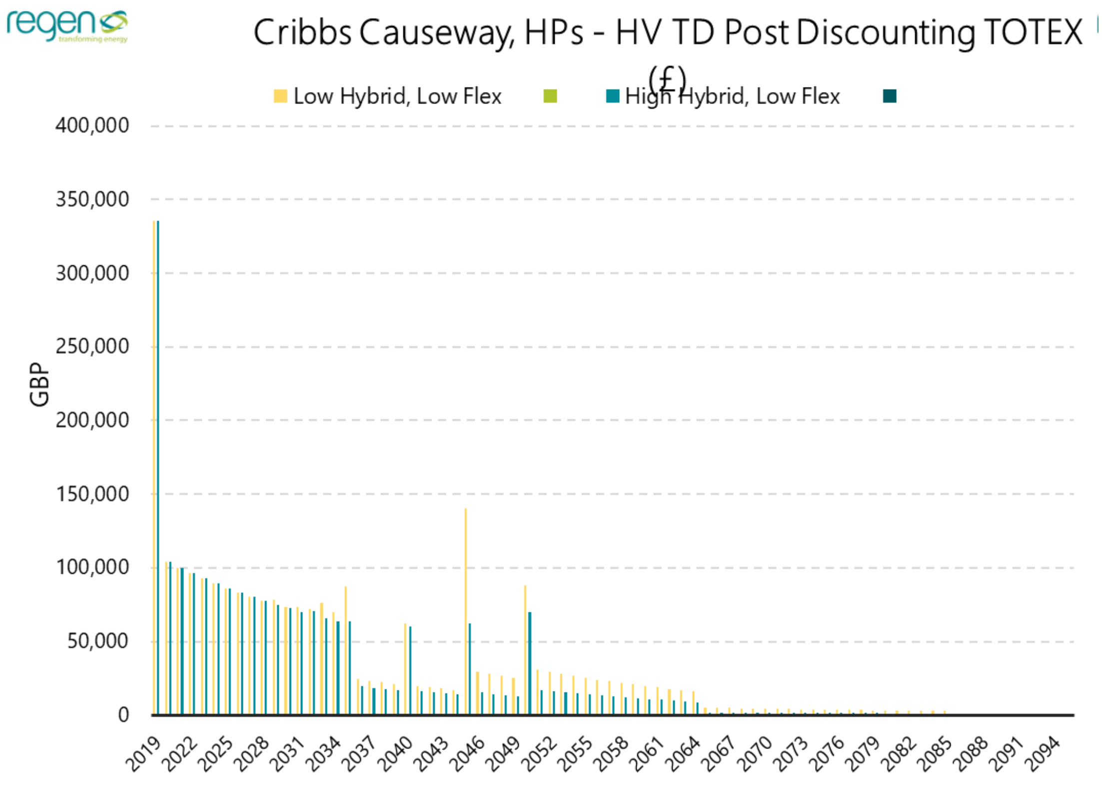


*Figure 55: Post Discounting HV TOTEX by year on the Cribbs Causeway primary, from top down analaysis*

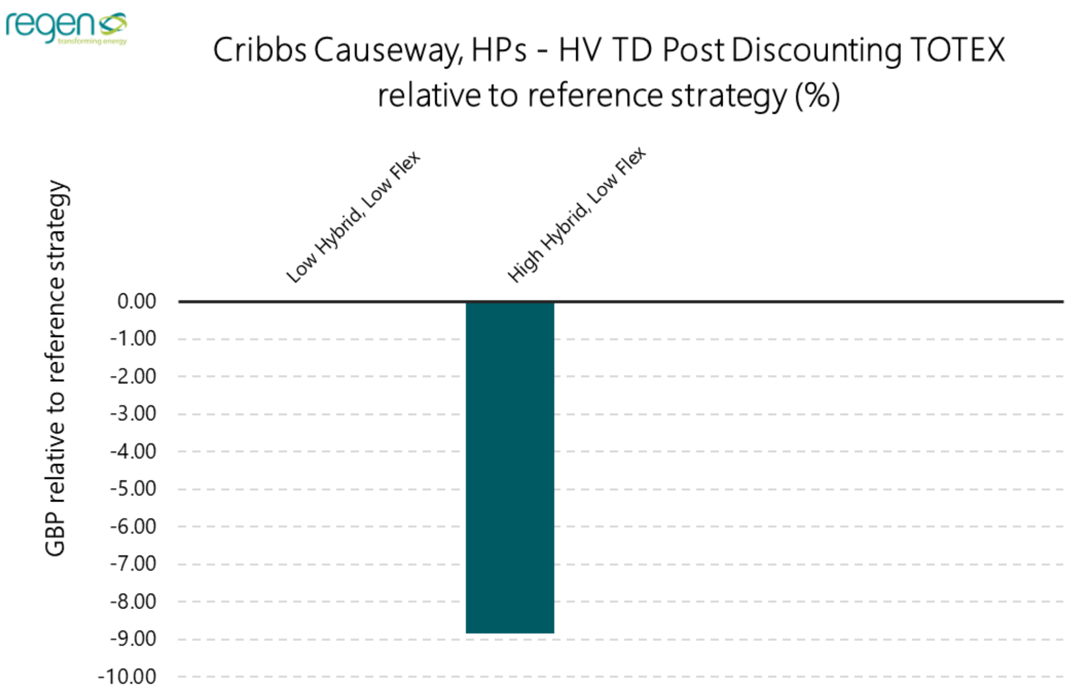


*Figure 56: Total Post Discounting HV TOTEX by 2050 on the Cribbs Causeway primary, from top down analaysis*

# 8. APPENDIX 3: Nailsea significant results

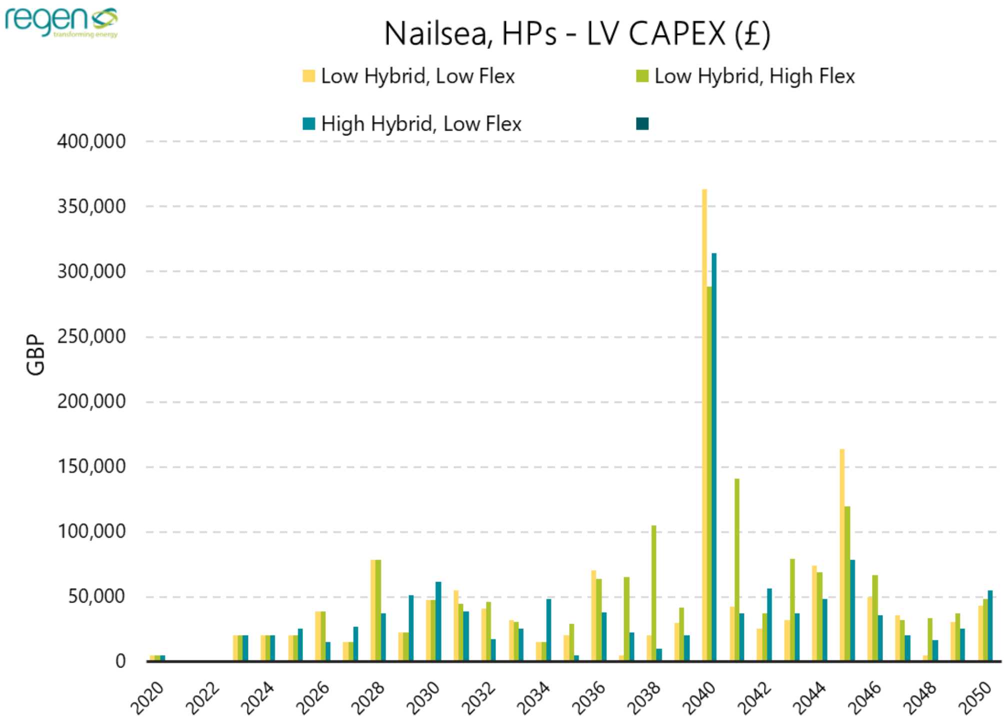


*Figure 57 LV CAPEX by year on the Nailsea primary*

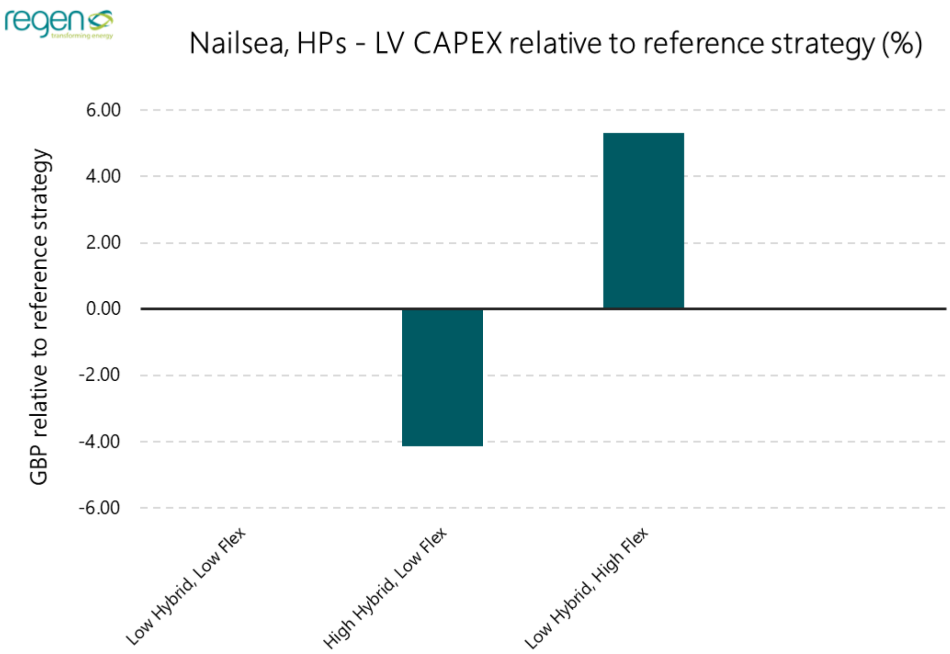


*Figure 58: Total LV CAPEX by 2050 on the Nailsea primary*

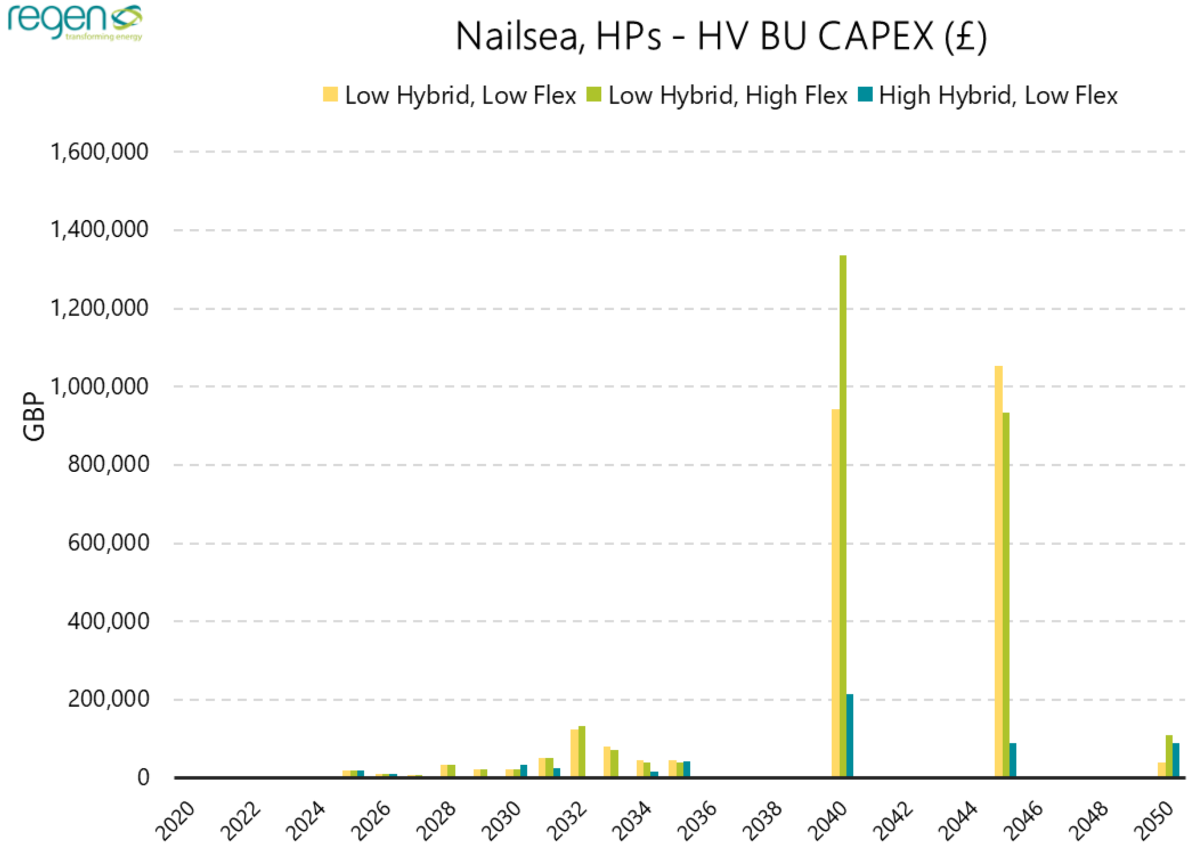


*Figure 59: HV CAPEX by year on the Nailsea primary, from bottom up analysis*

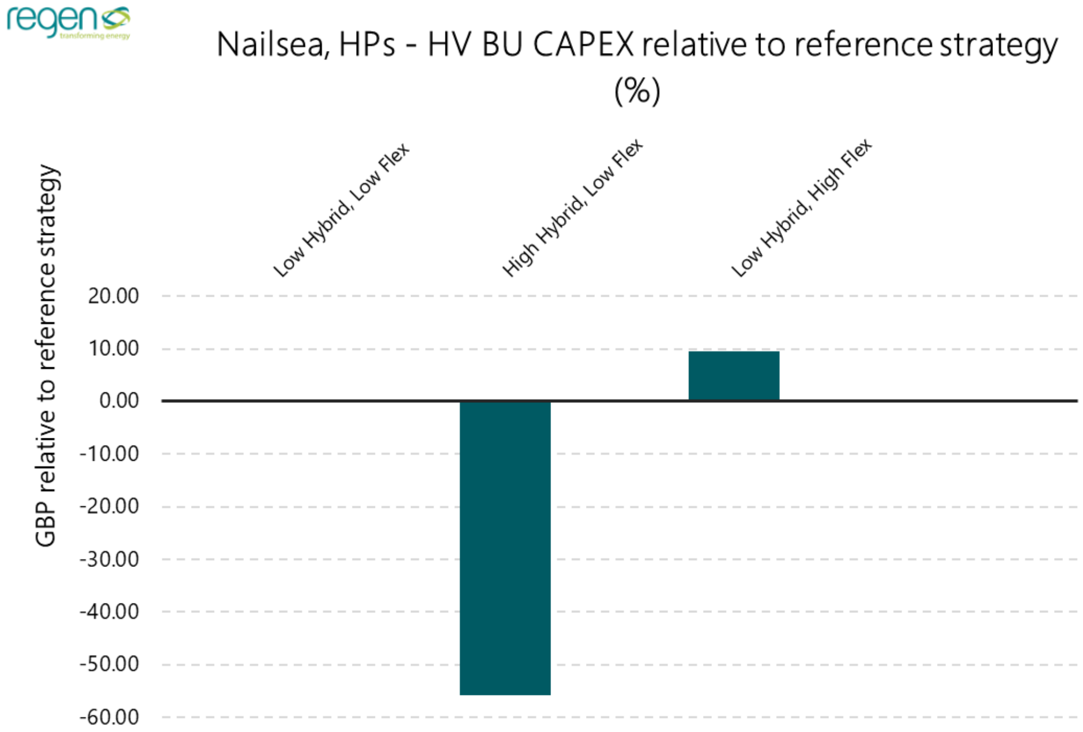


*Figure 60: Total HV CAPEX by 2050 on the Nailsea primary, from bottom up analysis*

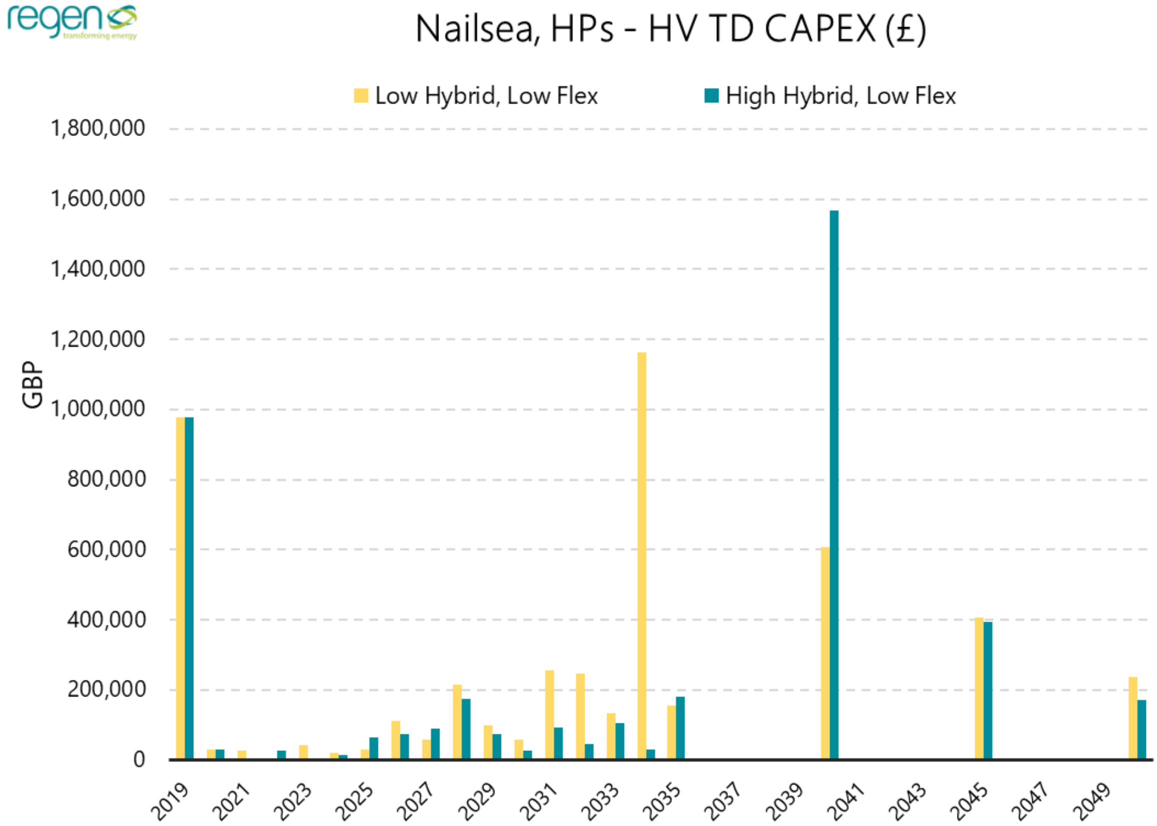


*Figure 61: HV CAPEX by year on the Nailsea primary, from top down analysis*

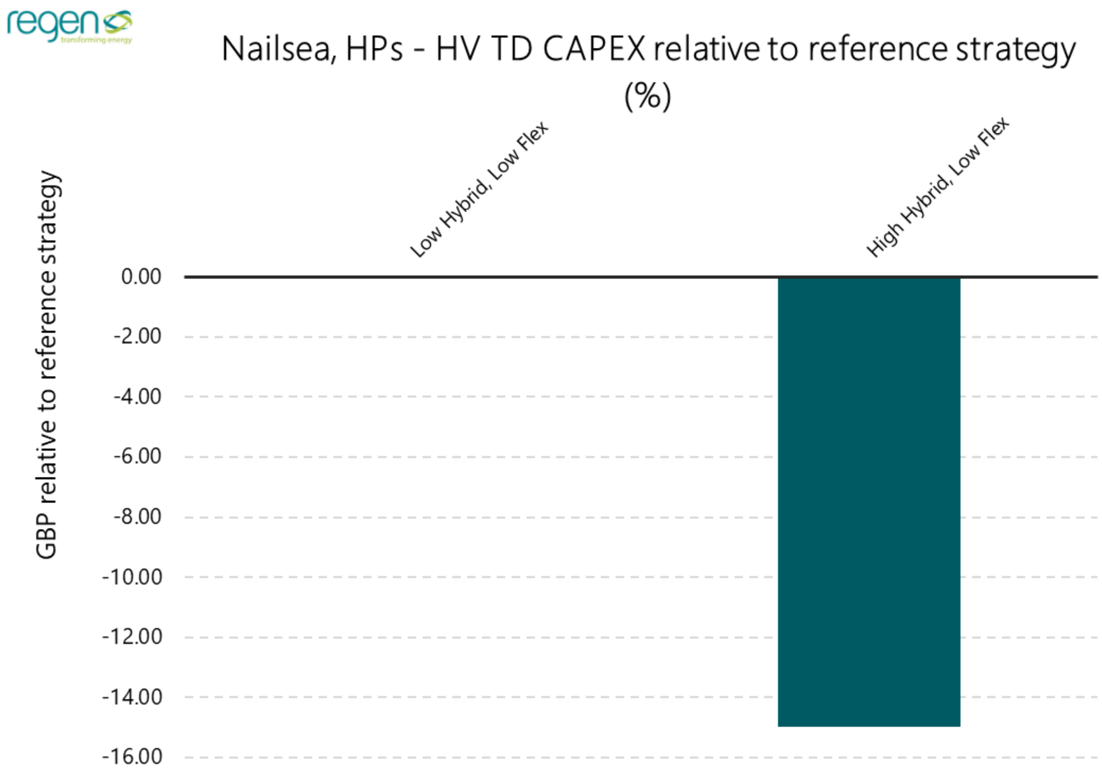


*Figure 62: Total HV CAPEX by 2050 on the Nailsea primary, from top down analaysis*

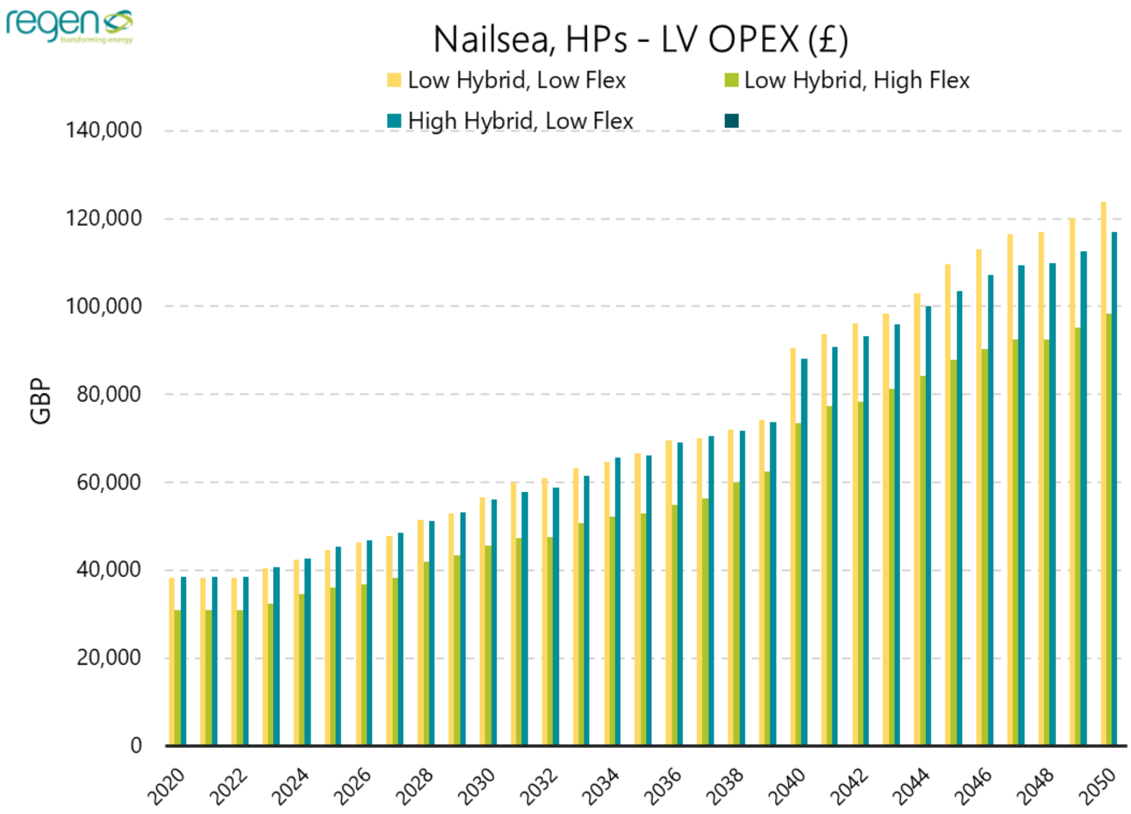


*Figure 63: LV OPEX by year on the Nailsea primary*

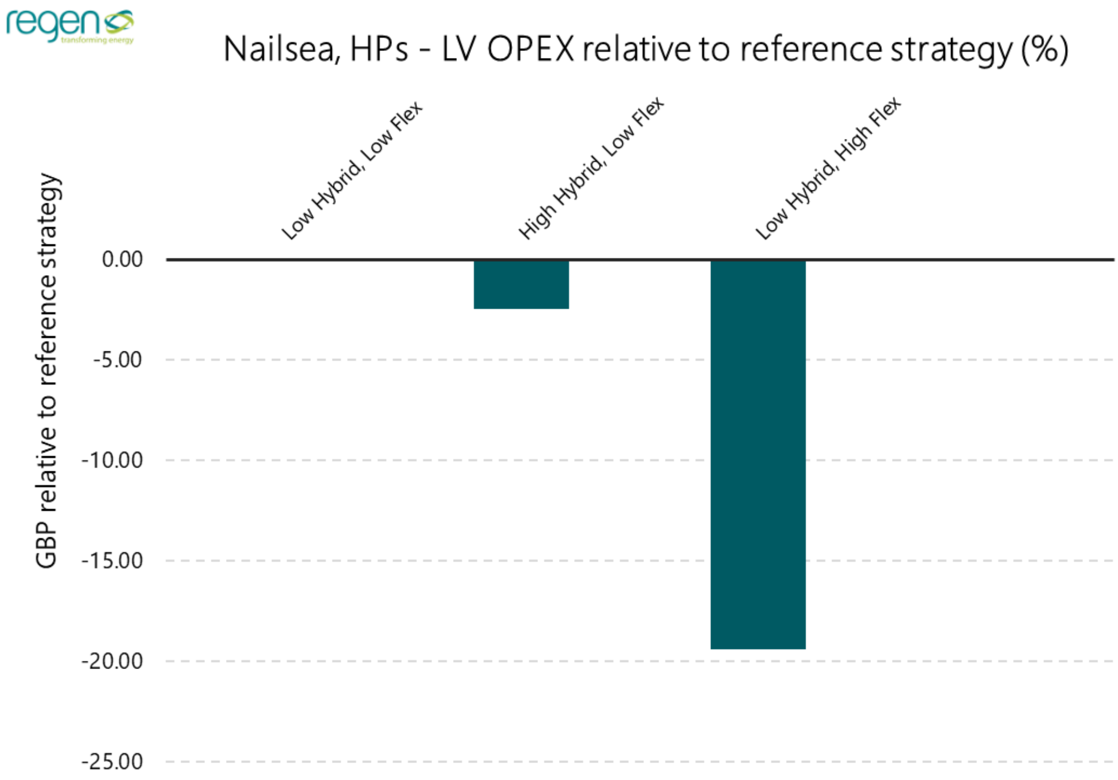


*Figure 64: Total LV OPEX by 2050 on the Nailsea primary*

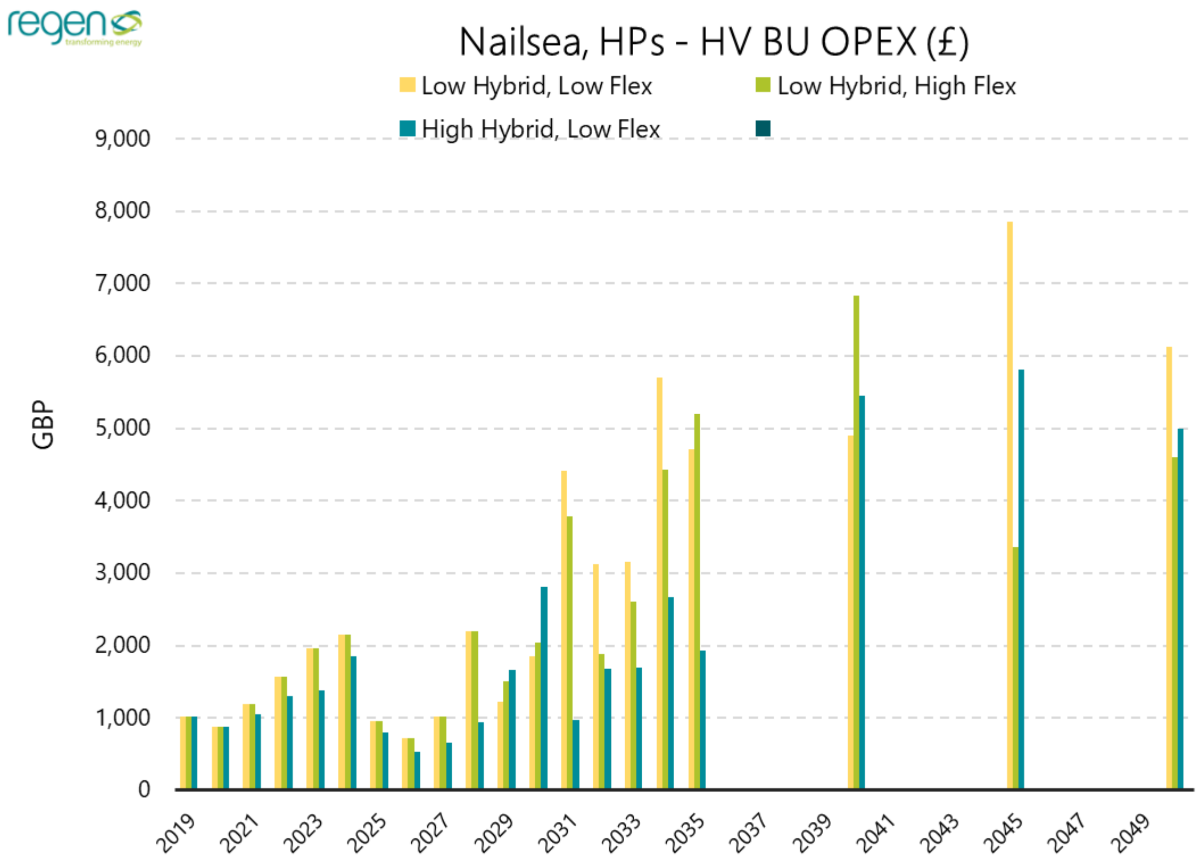


*Figure 65: HV OPEX by year on the Nailsea primary, from bottom up analysis*

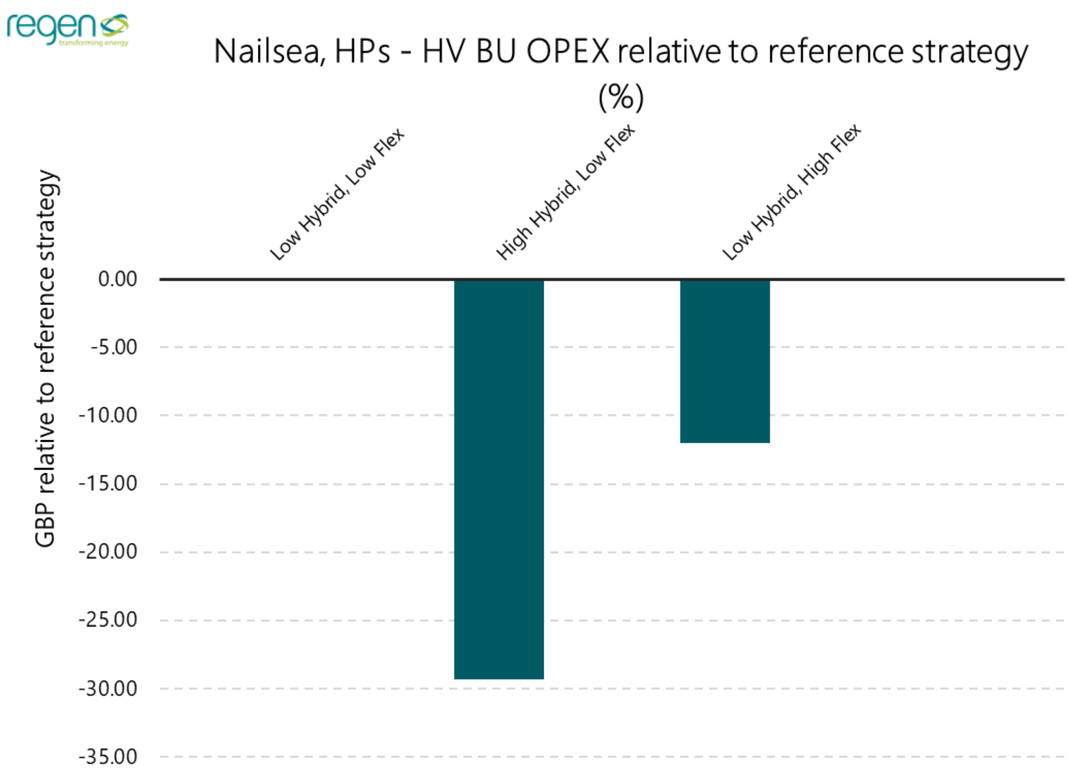


*Figure 66: Total HV OPEX by 2050 on the Nailsea primary, from bottom up analysis*

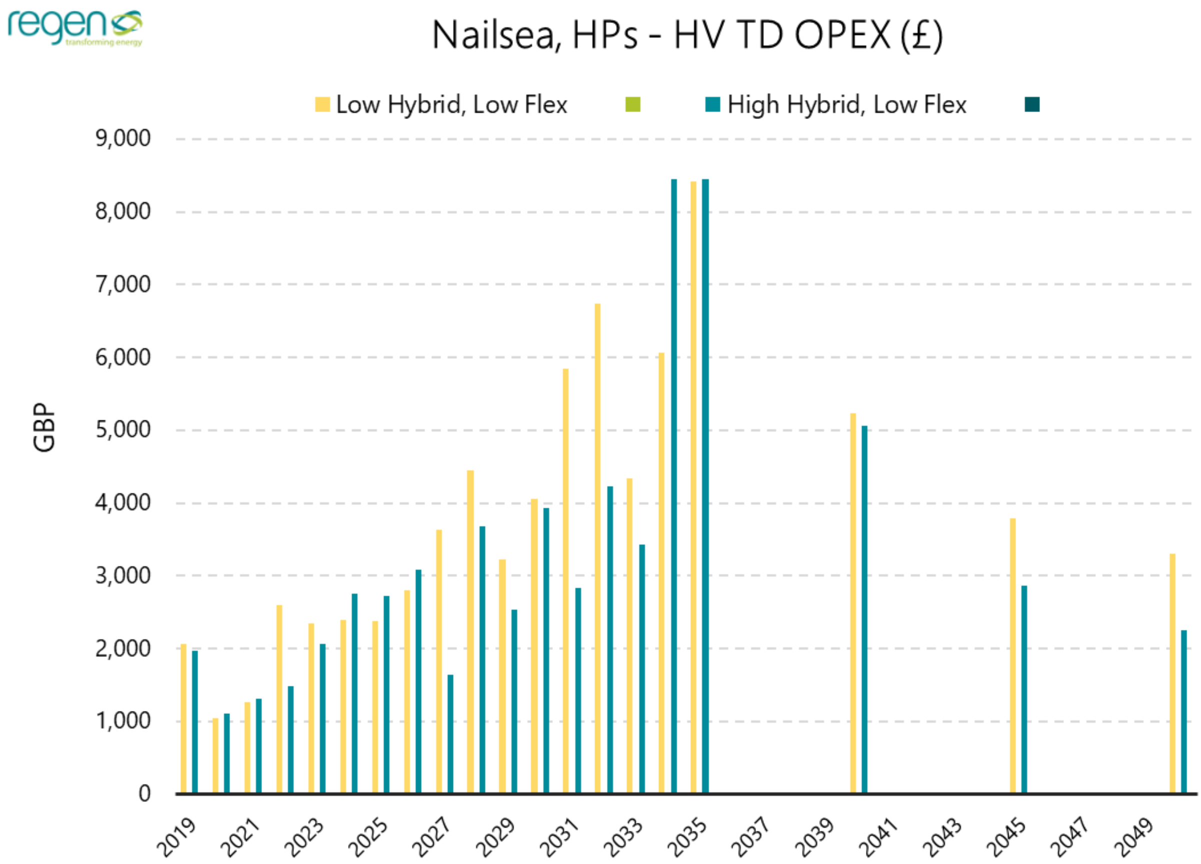


*Figure 67: HV OPEX by year on the Nailsea primary, from top down analaysis*

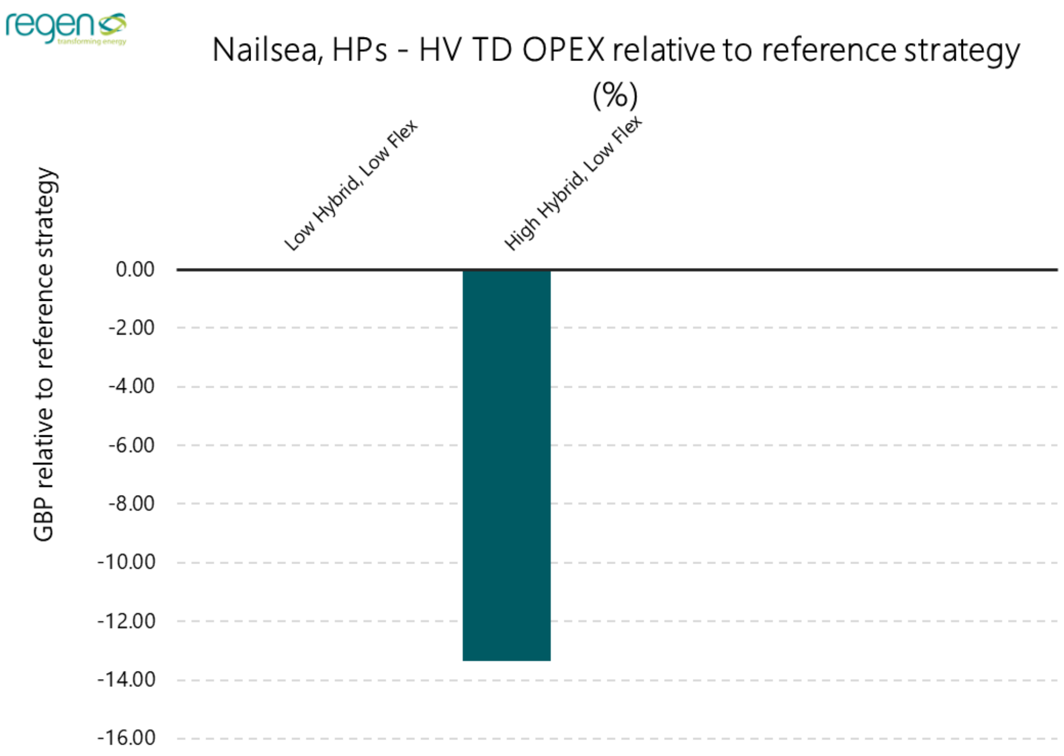


*Figure 68: Total HV OPEX by 2050 on the Nailsea primary, from top down analaysis*

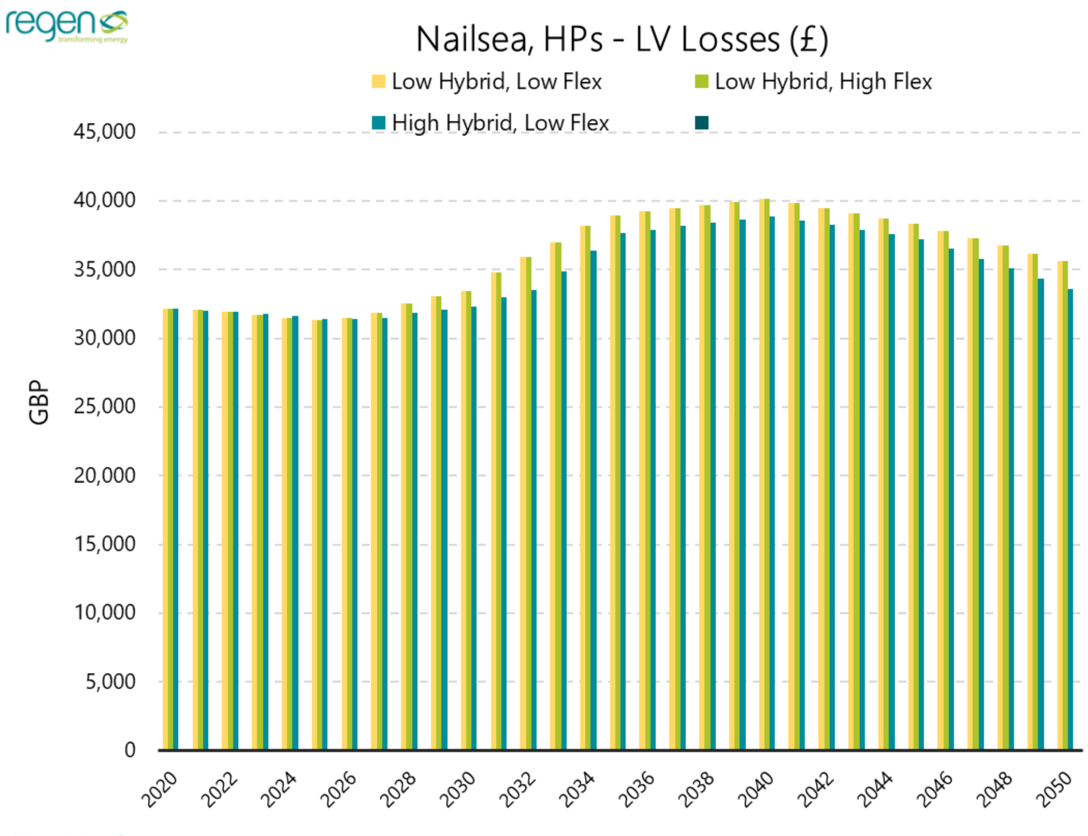


*Figure 69: LV Losses by year on the Nailsea primary*

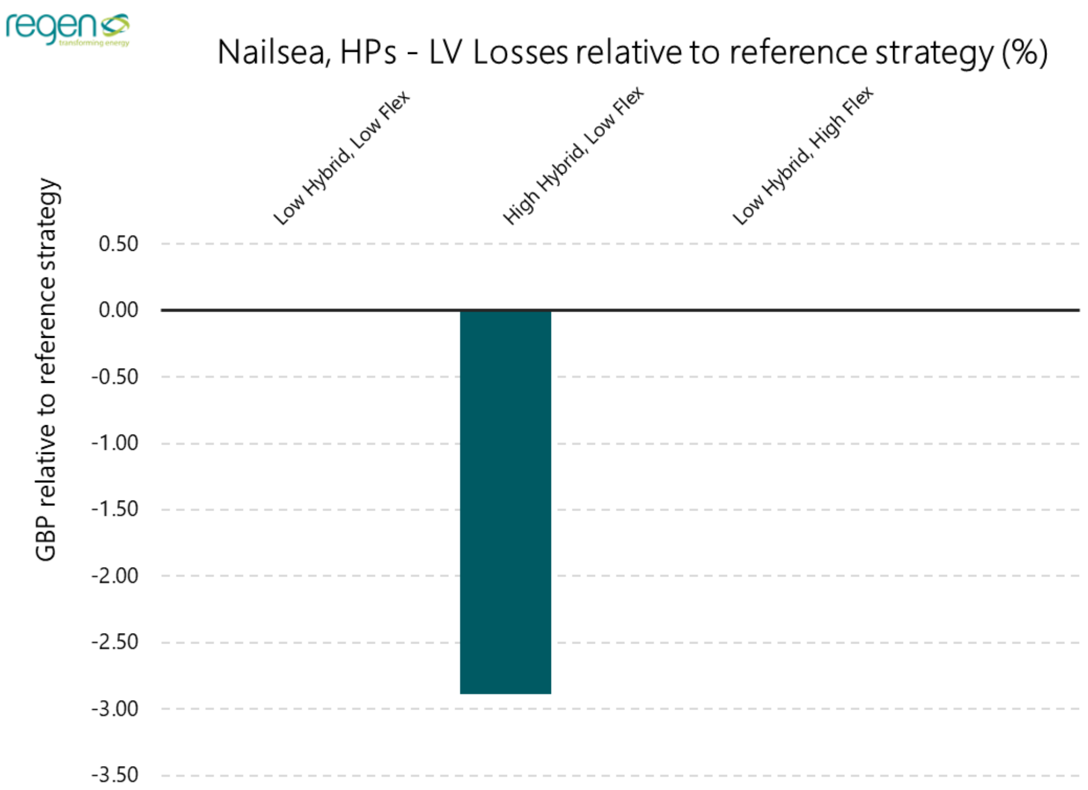


*Figure 70: Total LV Losses by 2050 on the Nailsea primary*

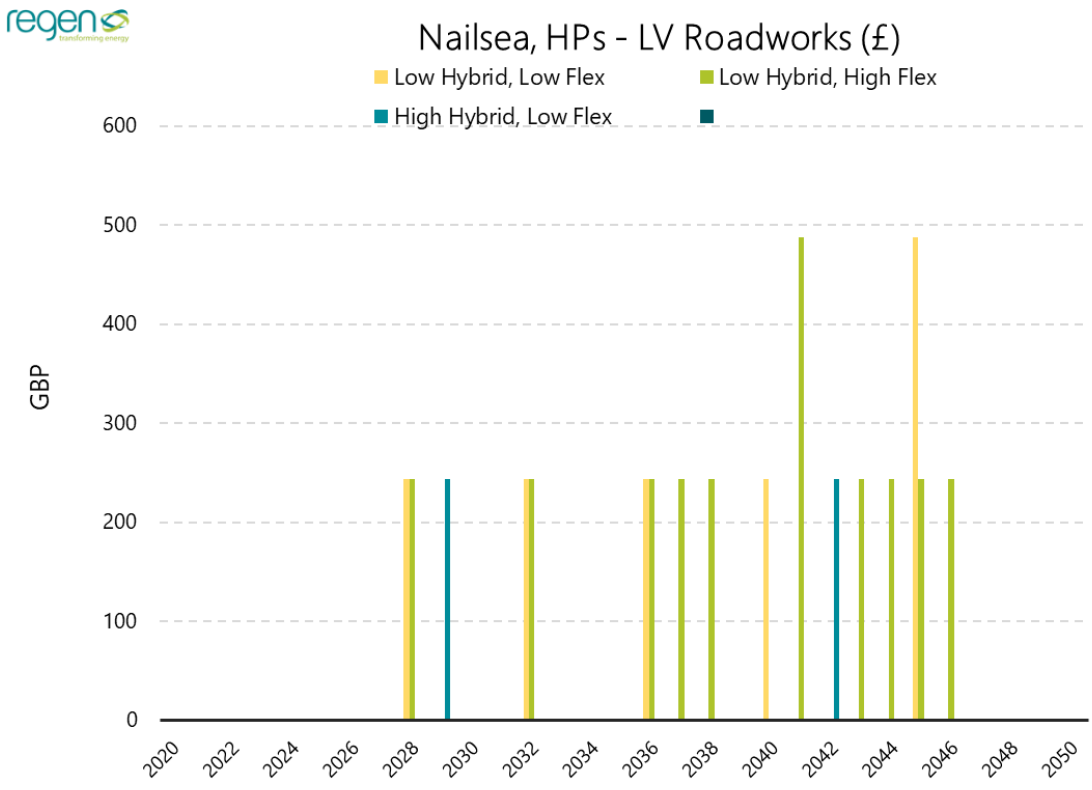


*Figure 71: LV roadworks by year on the Nailsea primary*

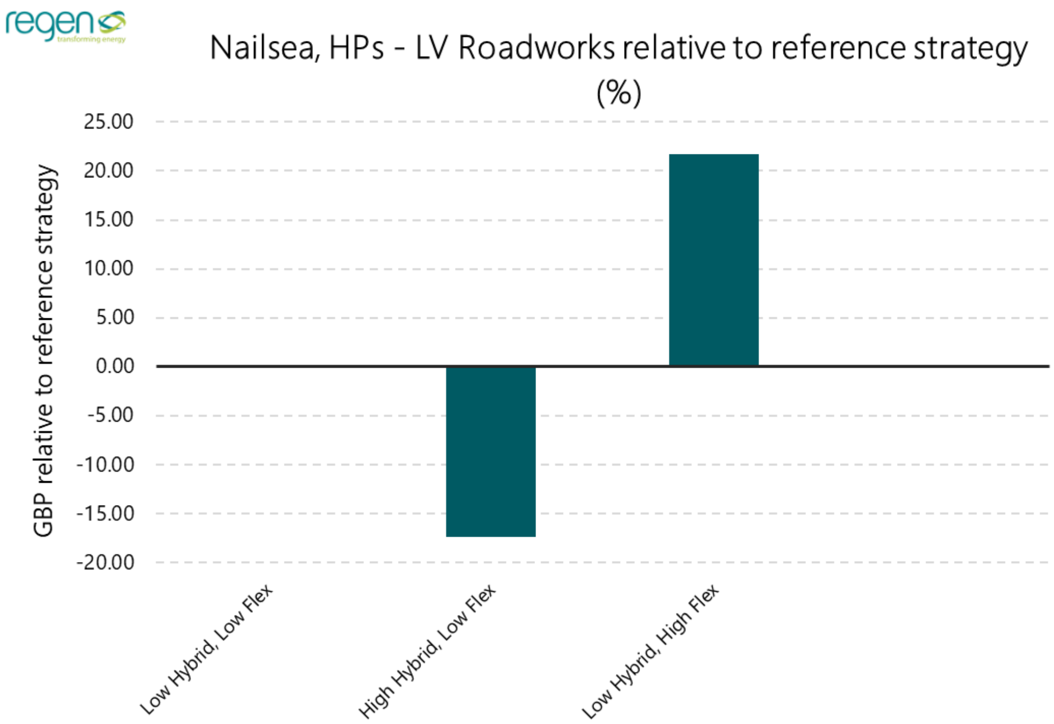


*Figure 72: Total LV roadworks by 2050 on the Nailsea primary*

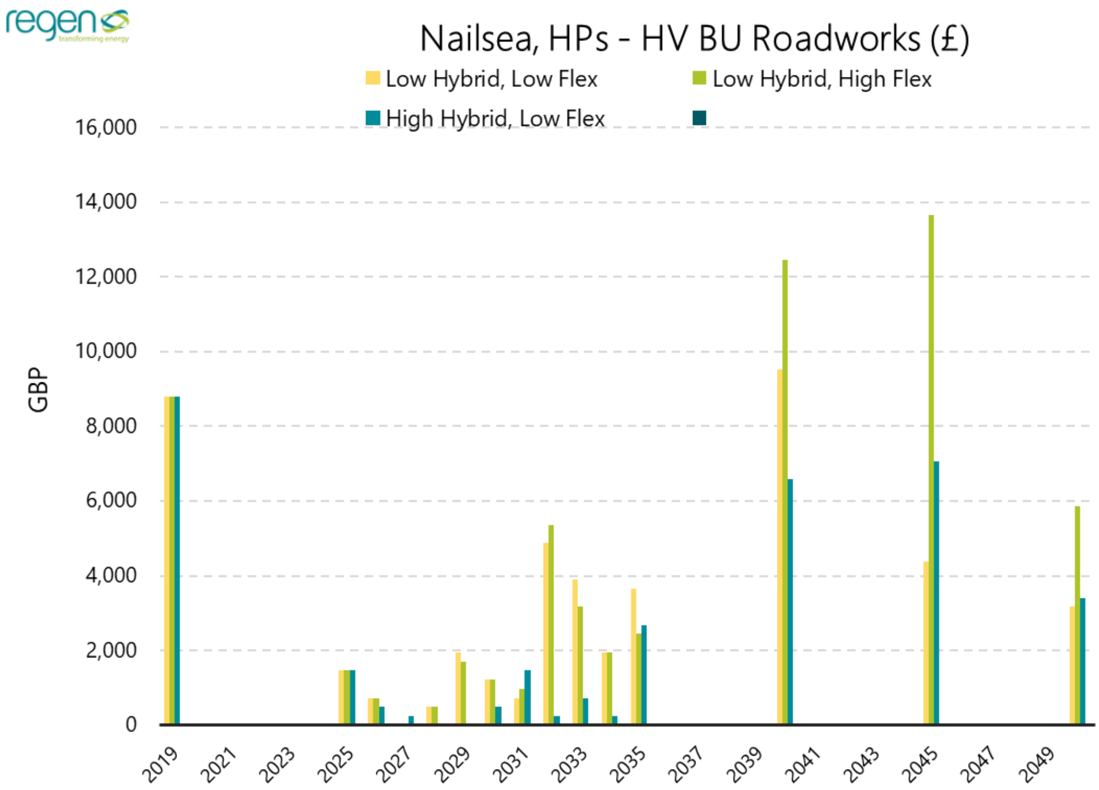


*Figure 73: HV roadworks by year on the Nailsea primary, from bottom up analysis*

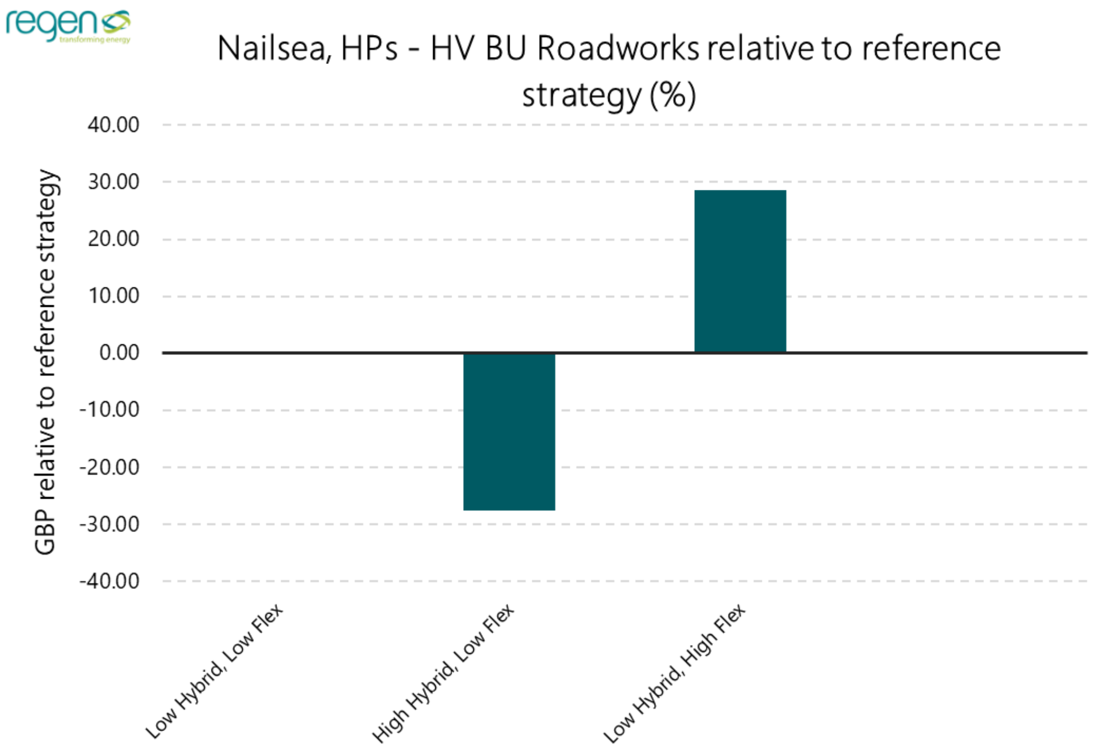


*Figure 74: Total HV roadworks by 2050 on the Nailsea primary, from bottom up analysis*

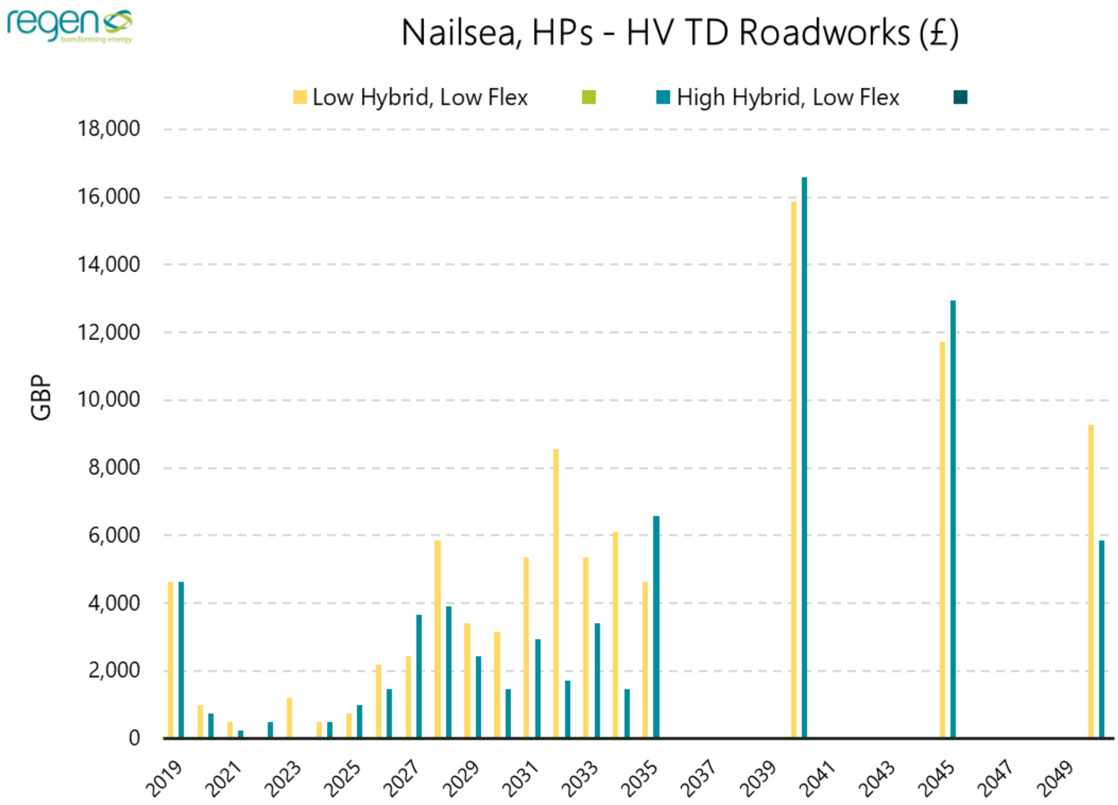


*Figure 75: HV roadworks by year on the Nailsea primary, from top down analaysis*

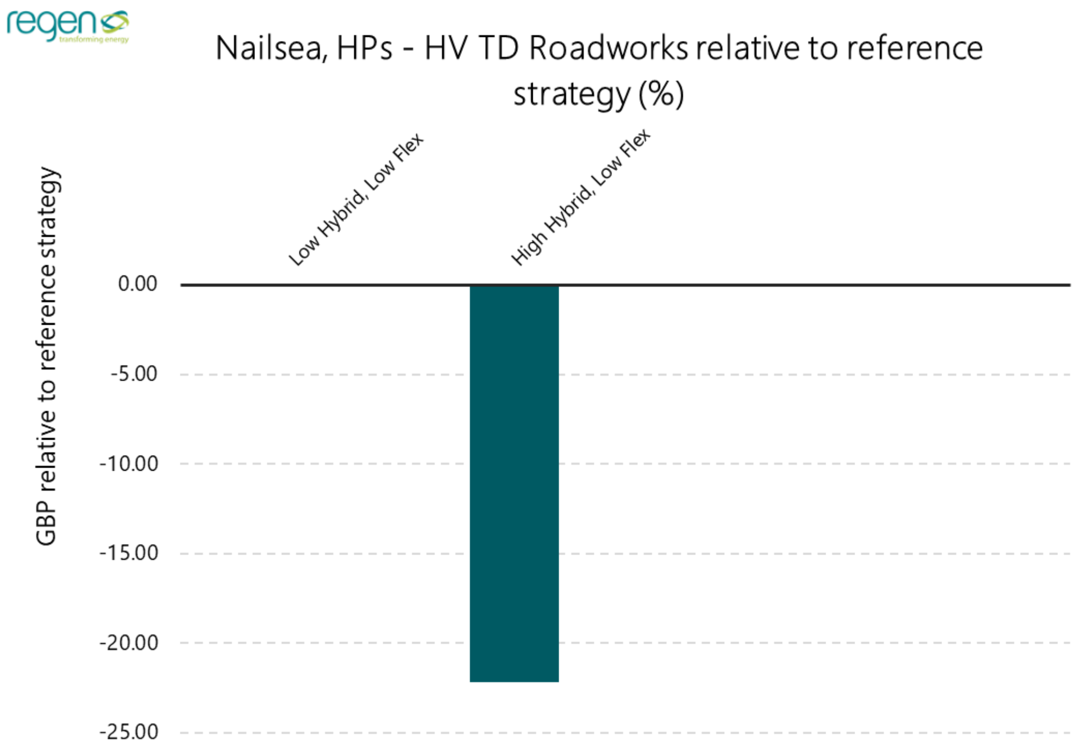


*Figure 76: Total HV roadworks by 2050 on the Nailsea primary, from top down analaysis*

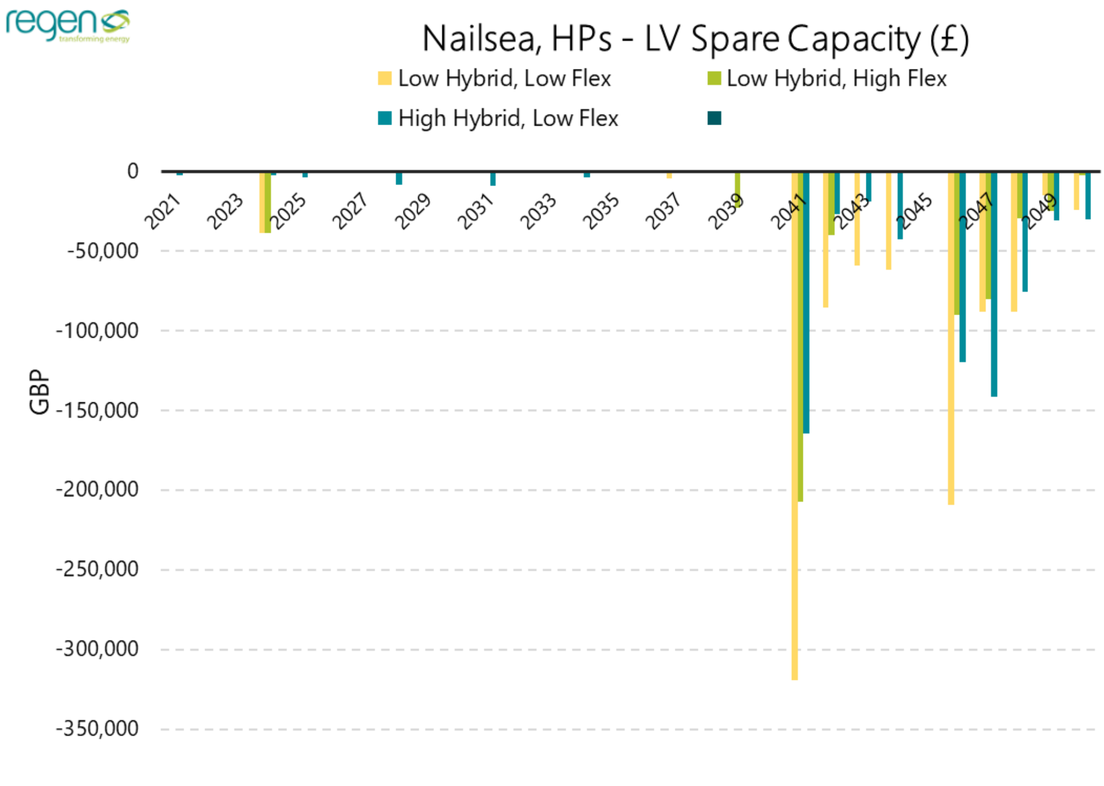


*Figure 77: LV Spare Capacity by year on the Nailsea primary*

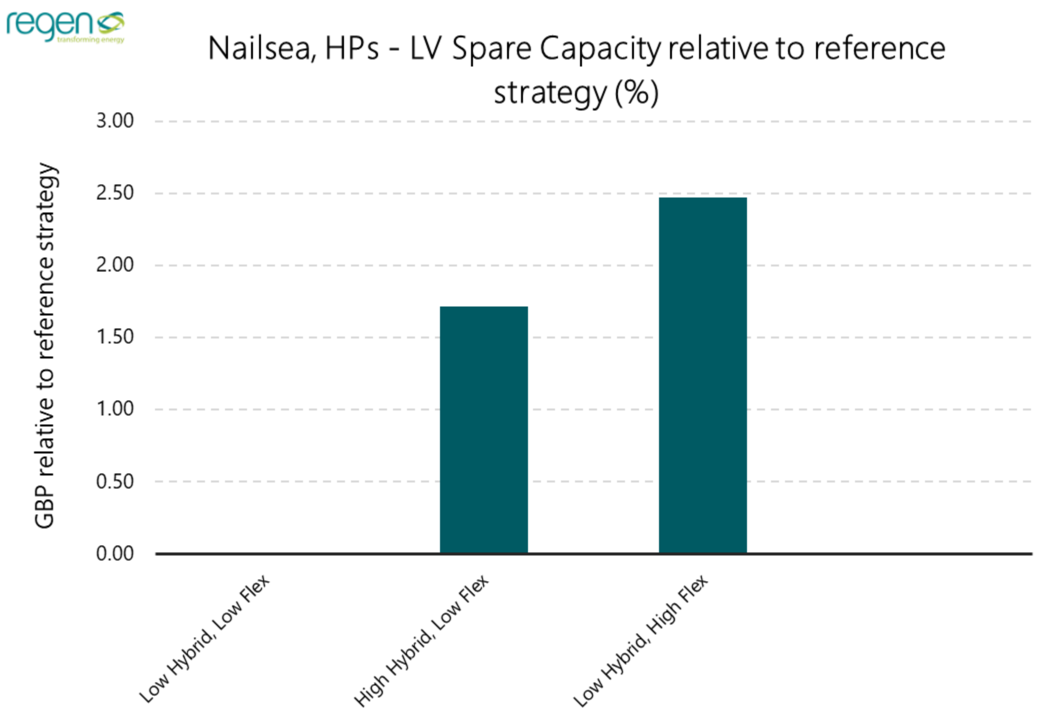


*Figure 78: Total LV Spare Capacity by 2050 on the Nailsea primary*

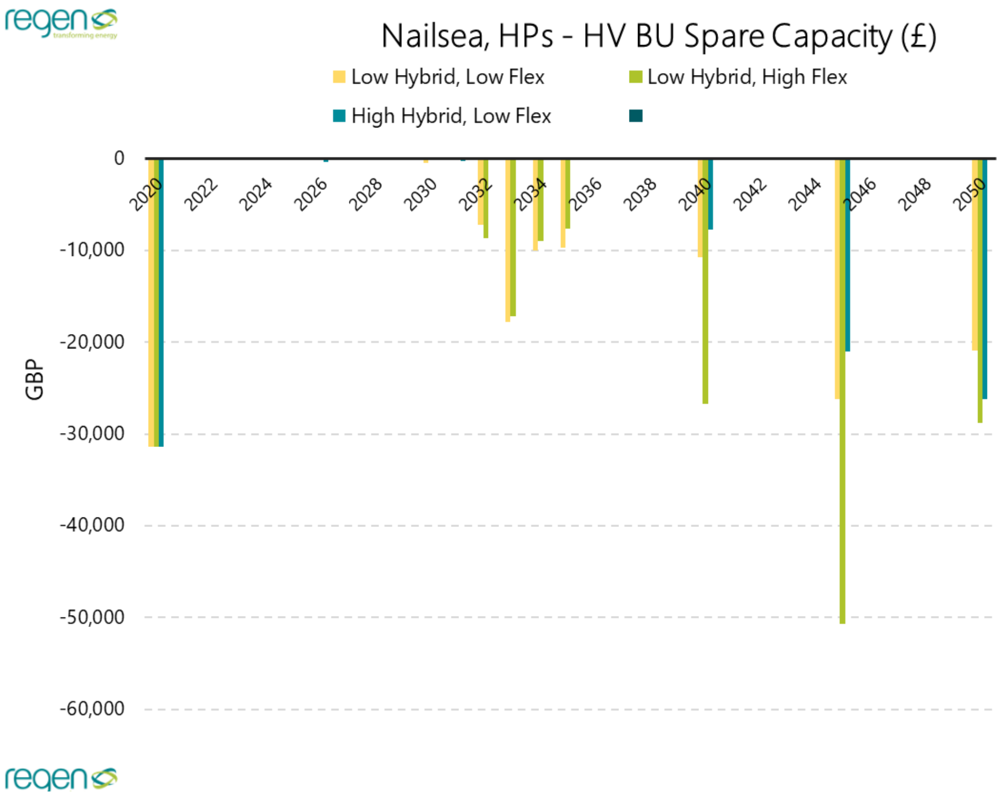


*Figure 79: HV Spare Capacity by year on the Nailsea primary, from bottom up analysis*

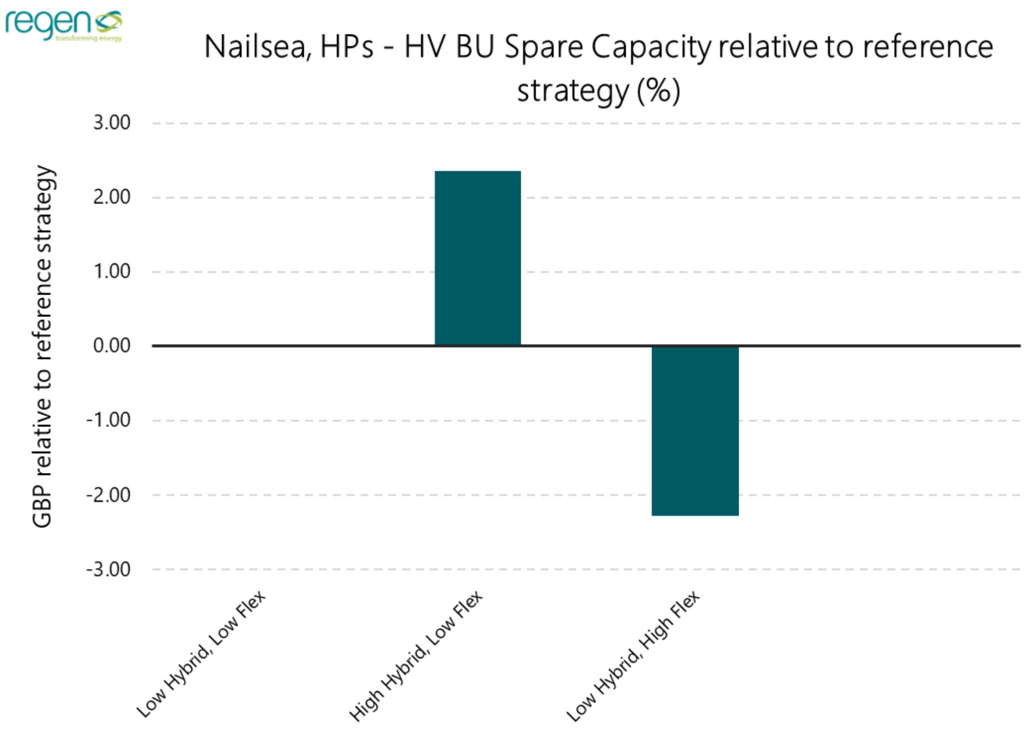


*Figure 80: Total HV Spare Capacity by 2050 on the Nailsea primary, from bottom up analysis*

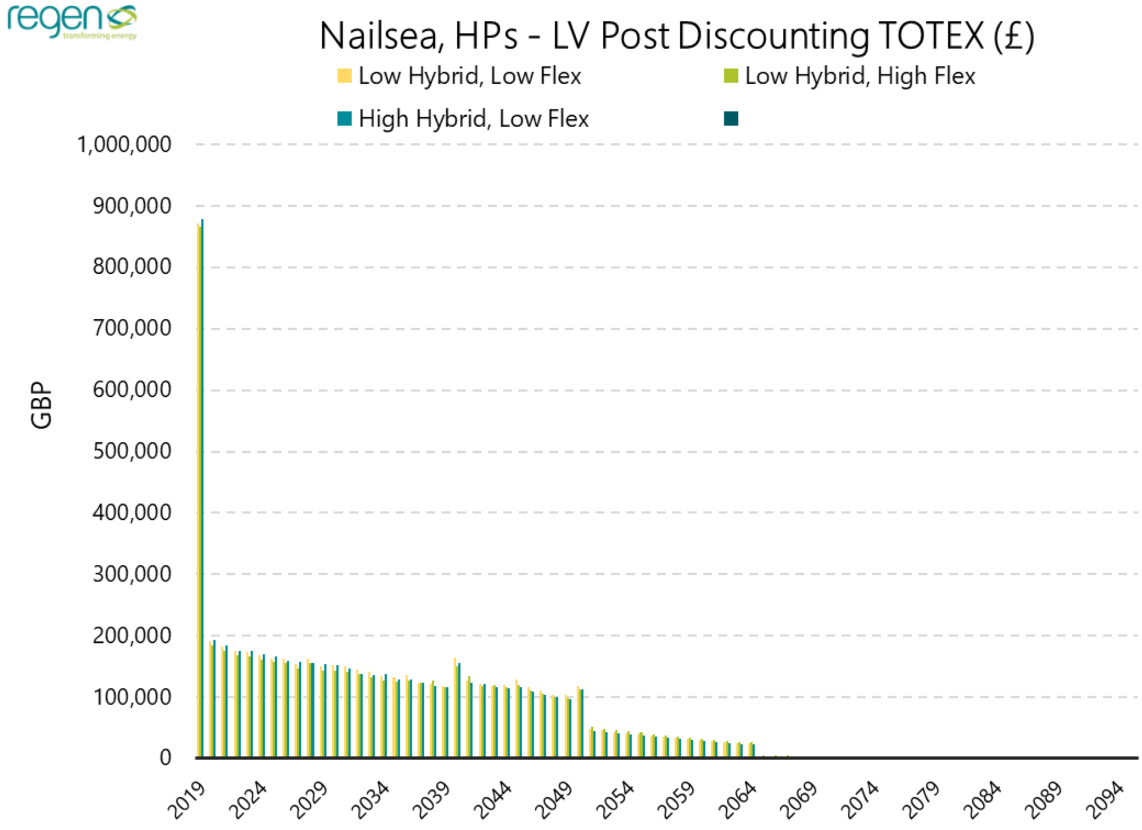


*Figure 81: Post Discounting LV TOTEX by year on the Nailsea primary*

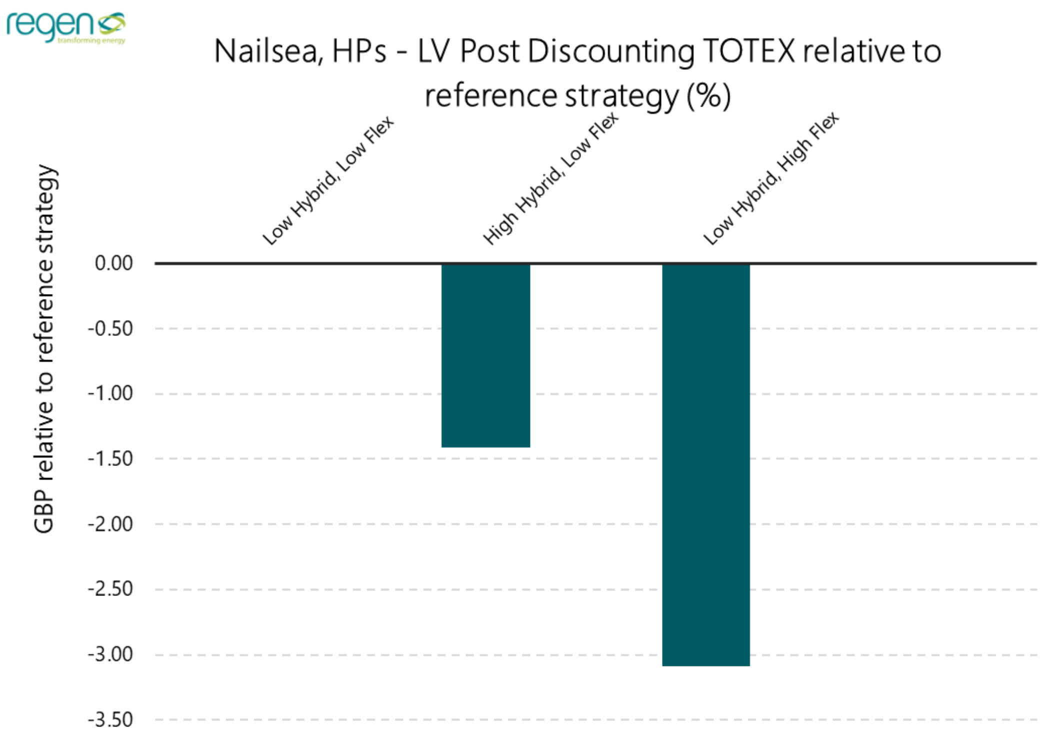


*Figure 82: Total Post Discounting LV TOTEX by 2050 on the Nailsea primary*

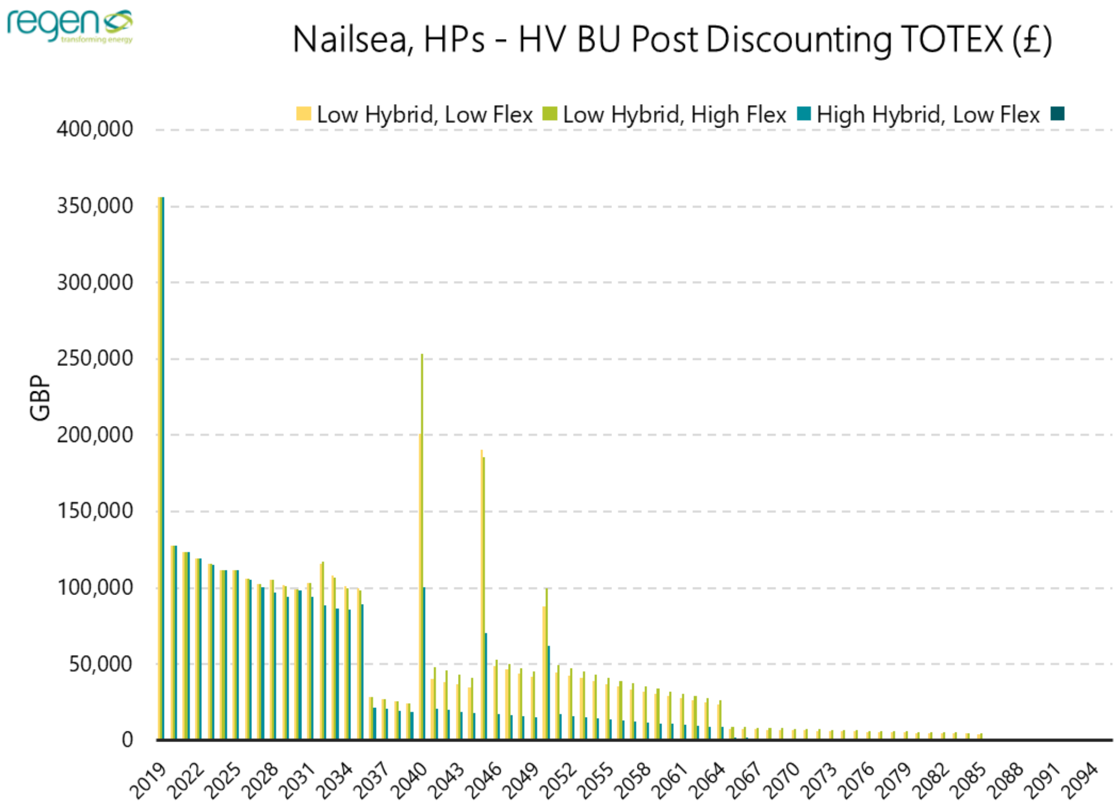


*Figure 83: Post Discounting HV TOTEX by year on the Nailsea primary, from bottom up analysis*

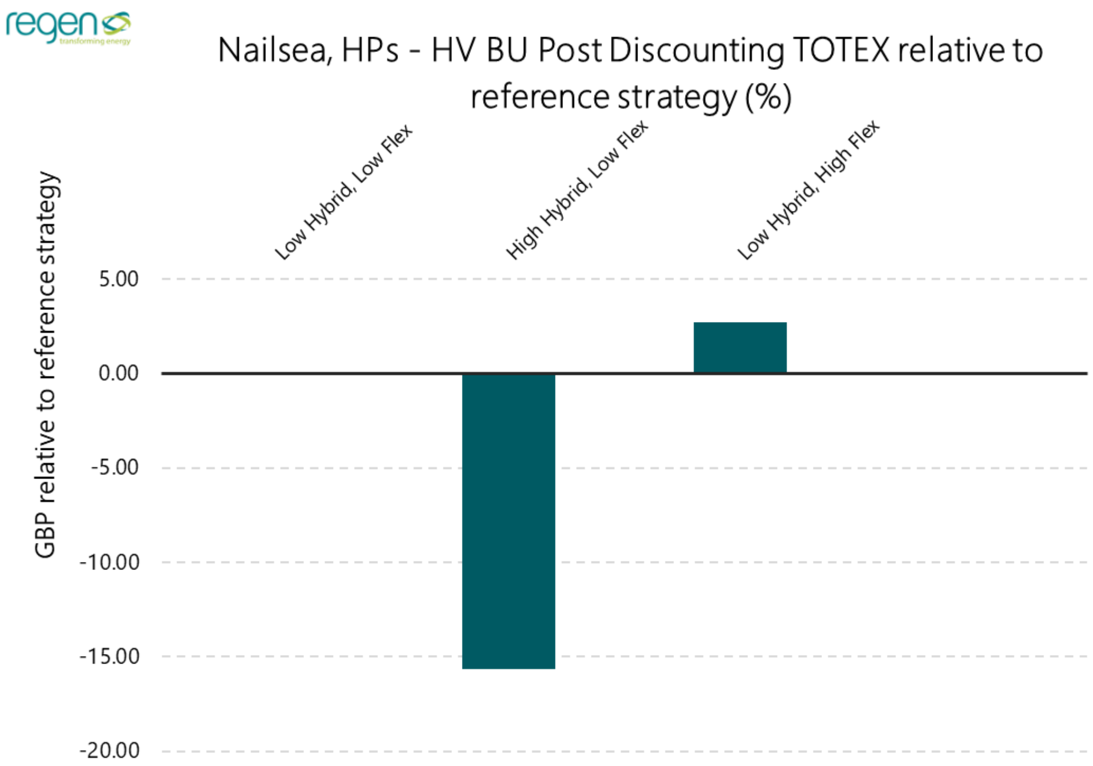


*Figure 84: Total Post Discounting HV TOTEX by 2050 on the Nailsea primary, from bottom up analysis*

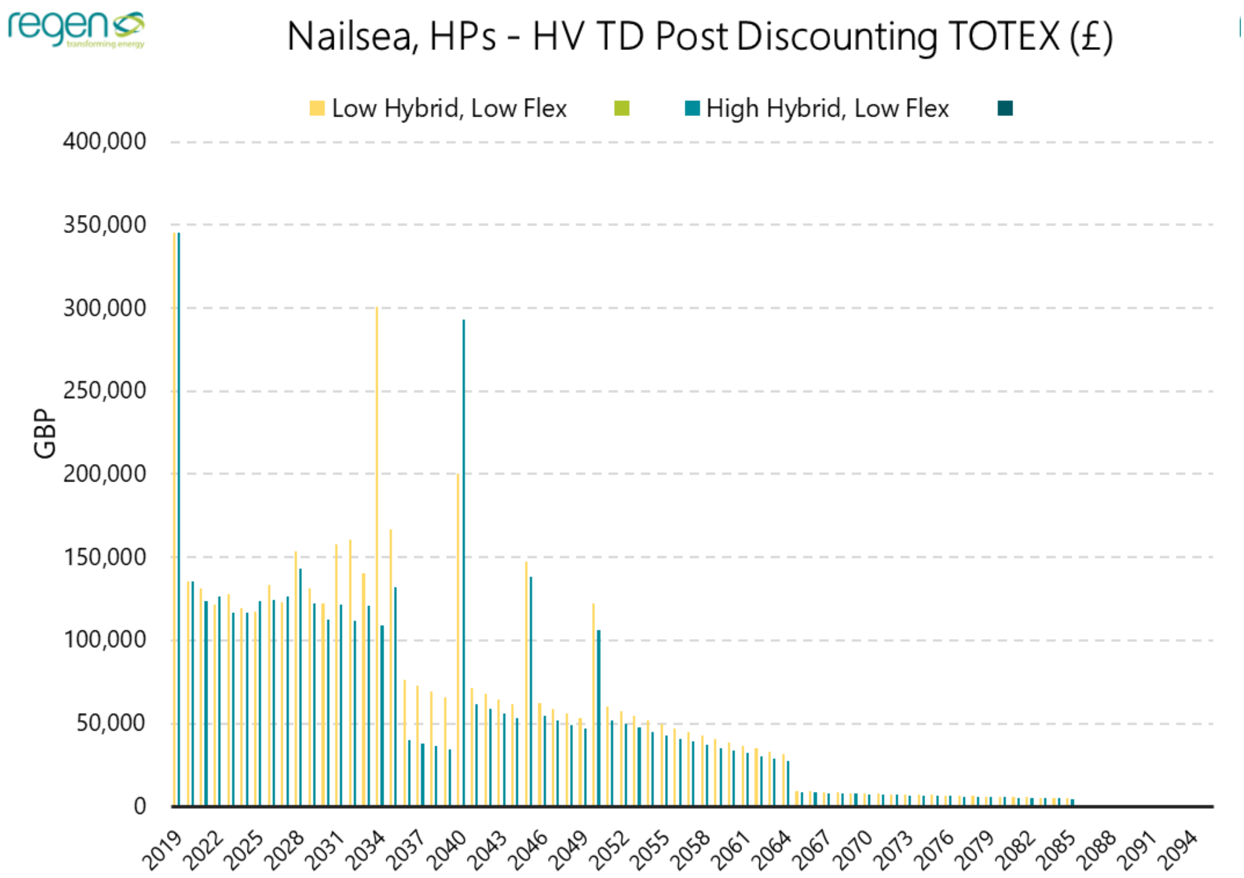


*Figure 85: Post Discounting HV TOTEX by year on the Nailsea primary, from top down analaysis*

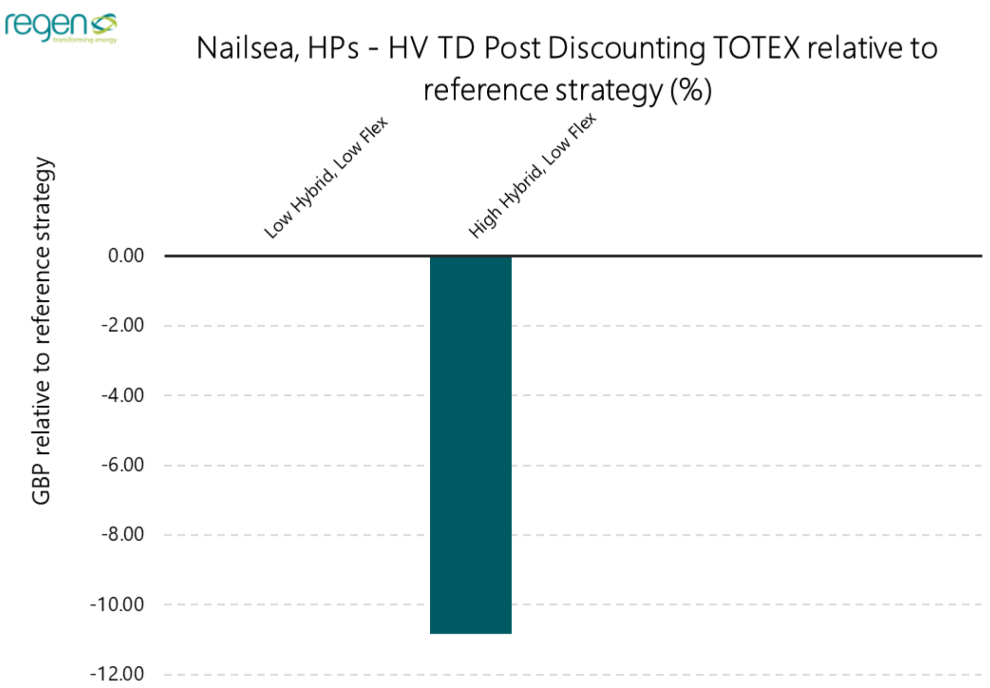


*Figure 86: Total Post Discounting HV TOTEX by 2050 on the Nailsea primary, from top down analaysis*

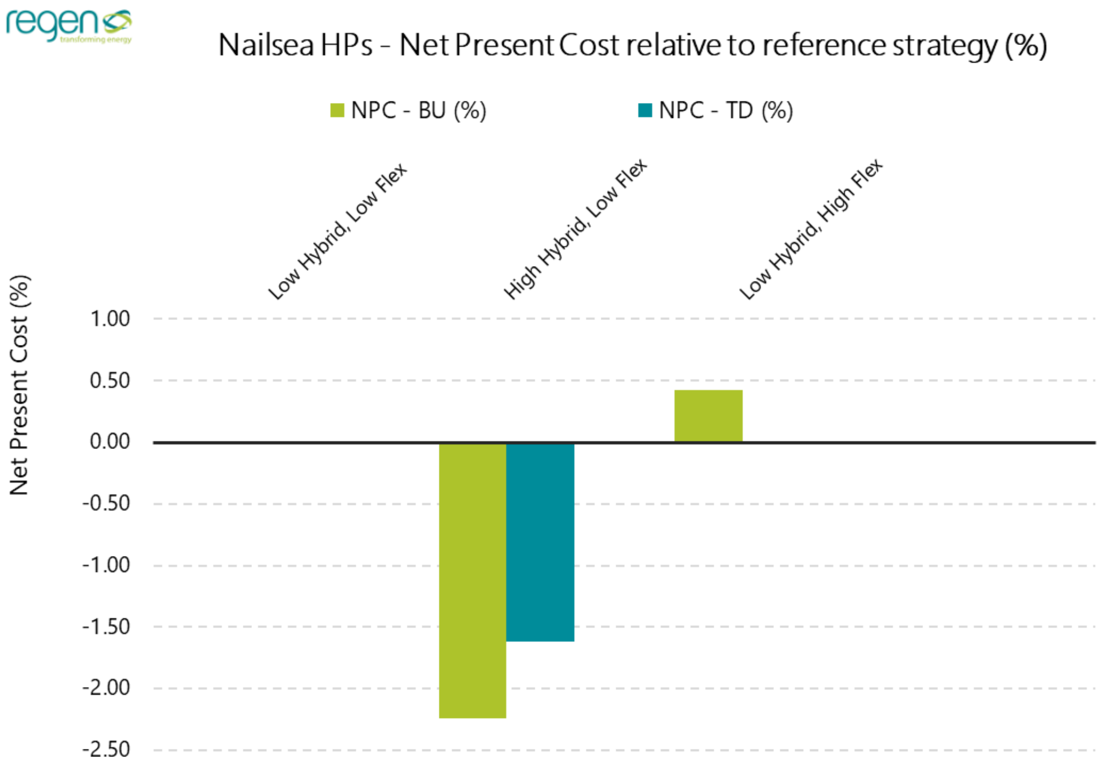


*Figure 87: Total NPC by 2050 on the Nailsea primary*

# 9. Appendix 4: Bath Enterprise Zone Heat Network sensitivity

Only a single, top-down, run of HV NAT was used to test the BEZ Heat Network sensitivity, there was no bottom up or LV analysis undertaken. The HV NAT run output no significant differences in HV network CAPEX, OPEX, losses or roadworks when compared to the base-case (Low hybrid heat pumps) run. This was because the heat network's assumed demand on the Dorchester St primary was equal to the multiple individual heat pumps it was replacing. With no LV impact assessment, there was not enough granularity to describing how the heat network would impact the network below the primary level.

This result, suggesting that the HV network would not be impacted by a heat network is a limited example based on a single option. Here, all heating demand from electrical heat pumps was replaced by a single electric heat network. In reality, a heat network will recycle an additional source of waste heat, and make savings in total electricity demand. Heat storage would also be employed to spread demand more evenly, reducing peak demand. As a results a heat network would likely reduce LV and HV electricity network costs.

This sensitivity has illustrated that heat networks require a greater degree of detail to be modelled well. Specifically, impacts on the LV network are key. You might expect to see large differences in LV network CAPEX, OPEX, losses and roadworks, from having a less highly distributed network. In addition, Heat Networks are likely to be highly individual, with different levels of electricity demand supported by a range of sources of waste heat; inclusion of these potential variables in the modelling is important.