Customer Load Active System Services (CLASS) Carbon Impact Assessment

Final Report

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CLASS Carbon Impact Assessment
Final Report

Contents

Tables

Figures

Carbon Accounting for Voltage Control and Reactive Power Services

1 Introduction

The CLASS project has trialled innovative transformer management techniques and provided multiple services to the network. It has aimed to demonstrate new ways of reducing both the costs and environmental impact of the distribution network.

The services delivered in the trial are:

1. Peak Demand Reduction (PDR) through voltage control, reducing the need for network reinforcement
2. Demand Response (DR) through voltage control, providing an alternative to existing balancing market provision
3. Reactive Power (RP) absorption, providing an alternative to existing network management methods

ENW pilot studies for LCNF bid submission suggested that the CLASS approach will realise a net reduction in carbon emissions over the 'business as usual' (BAU) means of providing these services. This report provides an overview of the Carbon Impact Assessment approach and findings across scales with full detail provided in three accompanying reports; i) *Model Development & Methodology*, ii) *Emissions Profiles*, and iii) *Results*. The implications are briefly discussed in the wider context of distribution networks, UK energy policy and climate change.

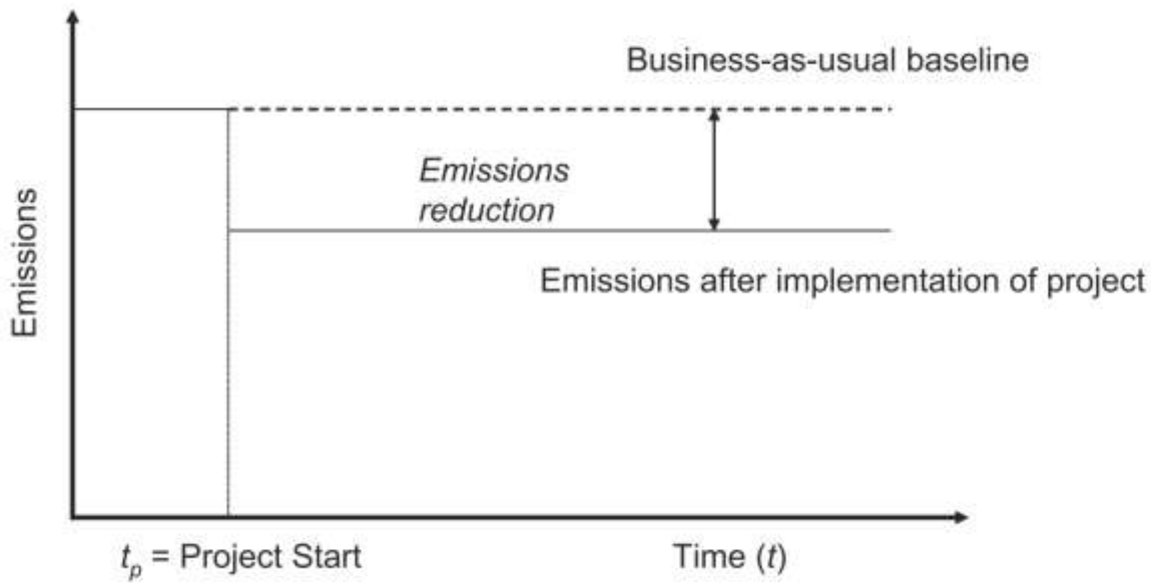
1.1 Headline Conclusions

1. Some aspects of the carbon impact of CLASS are sensitive to future circumstances and conditions. As such a scenarios approach has been adopted to investigate the scale, magnitude and direction of each of the carbon impacts under different plausible assumptions of the future.
2. CLASS could reduce the carbon impact of demand response (DR) and reactive power (RP) provision substantially, if energy demand reduction is realised in addition to power reduction. It is the continuous operations impacts category that provides the dominant DR and RP carbon benefit, rather than the asset deployment reduced or deferred.
3. On a national scale, the total benefits from both the DR and RP ancillary services could be as much as 116,000 tCO_2e per annum
4. When reinforcement is deferred due to use of the peak demand reduction (PDR) service additional losses are significant. This will result in an equivalent significant carbon penalty if the grid margin is provided by gas power stations (CCGTs) as is likely over the RIIO ED1 and ED2 periods.
5. This further example of carbon accounting for distribution network infrastructure will contribute to the academic body of knowledge in an under-researched area.

1.2 CLASS Services and BAU Alternatives

It should always be remembered that the calculation of emissions reductions is made against a 'business as usual' alternative case for each of the services offered. The UN Clean Development Mechanism (CDM), a carbon trading framework within the legally binding international climate change regime, has guided the development of the CLASS Carbon Impact Assessment methodology.

Emissions reduction project calculations quantify the difference between the project implemented and an alternative "business-as-usual" (BAU) baseline. This structure can be illustrated diagrammatically:



The carbon impact of each CLASS service, CI_{PDR}, CI_{DR} and CI_{RP}, provided over *n* years is therefore generalised as:

$$CI_{Service} = \sum_{t=t_p}^{n} BE_t - CE_{Service,t}$$

Where:

BE_t	=	Emissions from BAU baseline network configuration in year t, tCO_2e
$CE_{Service,t}$	=	Emissions from network delivering CLASS service in year t, tCO_2e

The BAU baseline is different for each service and has been compared to data gathered during the CLASS trials.

The BAU cases for the provision of each of the distinct CLASS Project services are:

1. Peak Demand Reduction (PDR), due to voltage reduction delivered by on load tap changers (OLTC); BAU is taken as traditional reinforcement with upgrades to 2x23MVA transformers at all sites (other possibilities identified and eliminated on a circuit by circuit basis).

2. Demand Response (DR), delivered by fast tripping of one of a pair of parallel transformers and OLTC actions; BAU is taken as the marginal emissions factor of balancing market providers anticipated in 2020.
3. Reactive Power (RP) absorption, delivered by OLTC tap staggering; BAU is taken as the installation and operation of STATCOMs with equivalent capability.

1.3 CLASS Load Growth Scenarios

The UK's energy system is at the start of a period of substantial change on both supply and demand sides, within the electricity system and for other energy vectors, largely driven by the necessity of decarbonisation. The performance of network innovations cannot therefore be examined against a static background.

Four scenarios (See Fig 1) were developed describing four very different futures; a wide range of growth projections from 23.5% increase to -14.5% decrease in load with one example of flat near term growth giving way to very rapid increase in RIIO ED2. Full details are described in the *Model Development & Methodology* report.

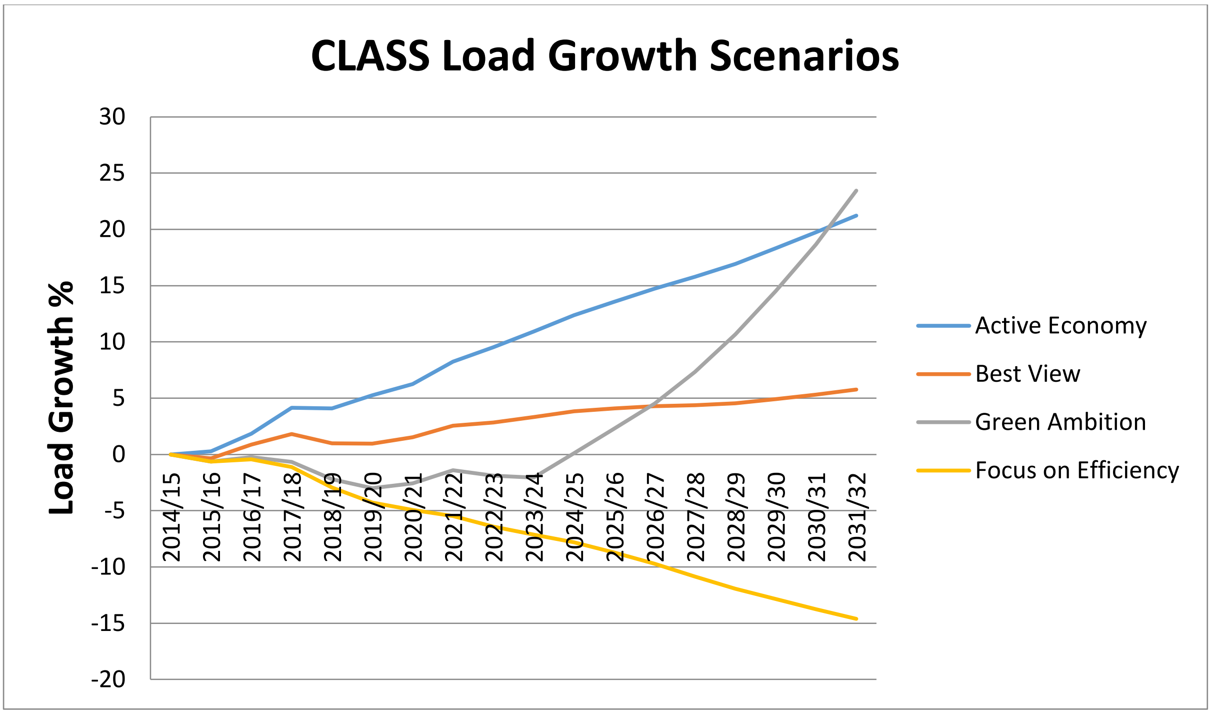


Figure 1 Scenarios of load growth examined in the Carbon Impact Assessment

Table 1 CLASS load growth scenario assumptions

Scenario	Background Growth	Low Carbon Technology Assumption
Active Economy	High	DECC Low 2014
Best View	Base	DECC Low 2014
Green Ambition	Low	DECC 1 2014

Focus on Efficiency	Low	Minimal

2 Peak Demand Reduction

Reducing voltage at peak times reduces the current flow and thermal stress on substations and other low voltage assets such that they do not require immediate replacement or reinforcement. The other work packages have shown that the CLASS solution is able to reduce peak load by 6% without adverse consequences for consumers or the transformers themselves. This reduction was applied to the load growth scenarios outlined above, Fig 1, and then to the substations within the Trial and the wider ENW network to assess the impact of the CLASS solution under a range of possible future circumstances.

Each of the modelled substations on the ENW network was assessed for a likely scheme of reinforcement if network capacity was reached within the upcoming RIIO periods, ED1 (2015 to 2022) and ED2 (2023 to 2031). Carbon impacts were counted if the application of CLASS was able to defer reinforcement at a substation for three years or greater.

2.1 Asset Carbon Impact

In each substation case assessed, the most likely asset reinforcement was found to be replacement of the existing transformers with a new pair of 23 MVA transformers and accompanying civil engineering works, including a concrete plinth. Example substation engineering drawings and specifications formed the basis of a materials inventory which as then converted to carbon impact equivalents using emissions factors from the University of Bath ICE v2.0 database (Hammond & Jones, 2011). The embodied carbon was estimated as 186 tonnes of carbon dioxide equivalent (tCO_2e) with the below split between sources. As was found in the previous ENW LCNF Tier 2 project, Capacity to Customers (C2C), the civil works are not negligible.

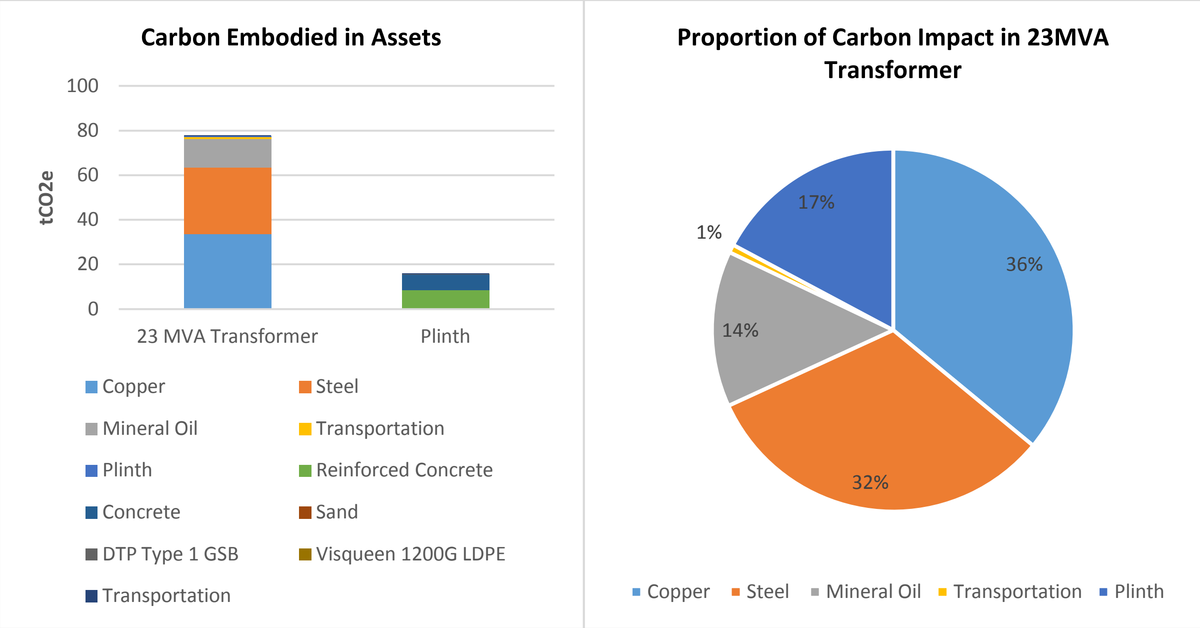


Figure 2 Asset Carbon Impact embodied in transformers

Where CLASS is implemented, a pair of Autonomous Substation Controllers (ASC) are added to the substation. These are small electronic switching devices with a low asset carbon impact estimated at 33 kgCO2e each. This is four orders of magnitude less than the deferred transformer reinforcement.

Table 2 CLASS Asset Carbon Impact estimates across scales

CLASS Asset Carbon Impact /tCO2e	**Individual ASC**	**CLASS Trial**	**ENW Network**	**GB Wide**
Autonomous Substation Controller (ASC)	0.03	4.0	20	224
Transport	0.001	0.1	0.5	5.5
Total	**0.03**	**4.1**	**21**	**230**

2.2 Operations Carbon Impact

CLASS Peak Demand Reduction (PDR) has a greater operations carbon impact than BAU. Simulations show 0.2% energy saving in the larger replacement transformers, due to reductions in winding resistance and leakage reactance (Chen & Li, 2012) and this difference was converted into a carbon dioxide equivalent at the anticipated UK grid marginal emissions factor. The losses energy requirement is assumed to be fulfilled by combined cycle gas turbine (CCGT) power plants, with a fuller discussion of the rationale for this and other emissions factors is given in the accompanying *Emissions Profiles* report.

Reductions in total consumer energy consumption due to PDR have not been calculated but are not expected to be comparable to transformer losses for two of reasons.

i. Reducing voltage and power at times of peak demand is a short duration measures whereas the benefit from reduced transformer losses is continuous.

ii. The nature of diverse consumer loads will determine whether power reduction leads to energy consumption reduction; a kettle will consume more energy at a lower voltage, a computer would be unaffected and an incandescent lightbulb will consume less.

2.3 Facilitated Carbon Impact

The CLASS solution has the potential to have broader effects on the ENW and GB grid, for instance, the rapid delivery of new network capacity without new physical assets removes the requirement for planning procedures and civil works. This in turn may result in additional indirect emissions reductions due to the reduced time to connection of high demand but low carbon technologies (LCT) such as electric vehicles (EVs) that might otherwise be delayed by constraints on the network.

Facilitated carbon impact was only estimated for the Green Ambition scenario where a rapid change in demand is included. Facilitated Carbon Impact across the trial were found to be negligible, approximately 3 tCO2e for the 60 circuits examined and 8 tCO2e for the whole of the ENW network. Furthermore, the complex chain of assumptions means that these benefits have a lower level of confidence than the more direct asset and operations impacts and there is the potential for double counting of reductions by both the LCT installer and ENW.

2.4 Net Carbon Impact

As outlined, the CLASS PDR service has two counteracting carbon impacts; it both defers asset reducing carbon embodied in their manufacture for a period of time, and increases emissions in operation due to increased losses relative to the installation of new transformers. This effect is best comprehended in terms of a time series as illustrated below.

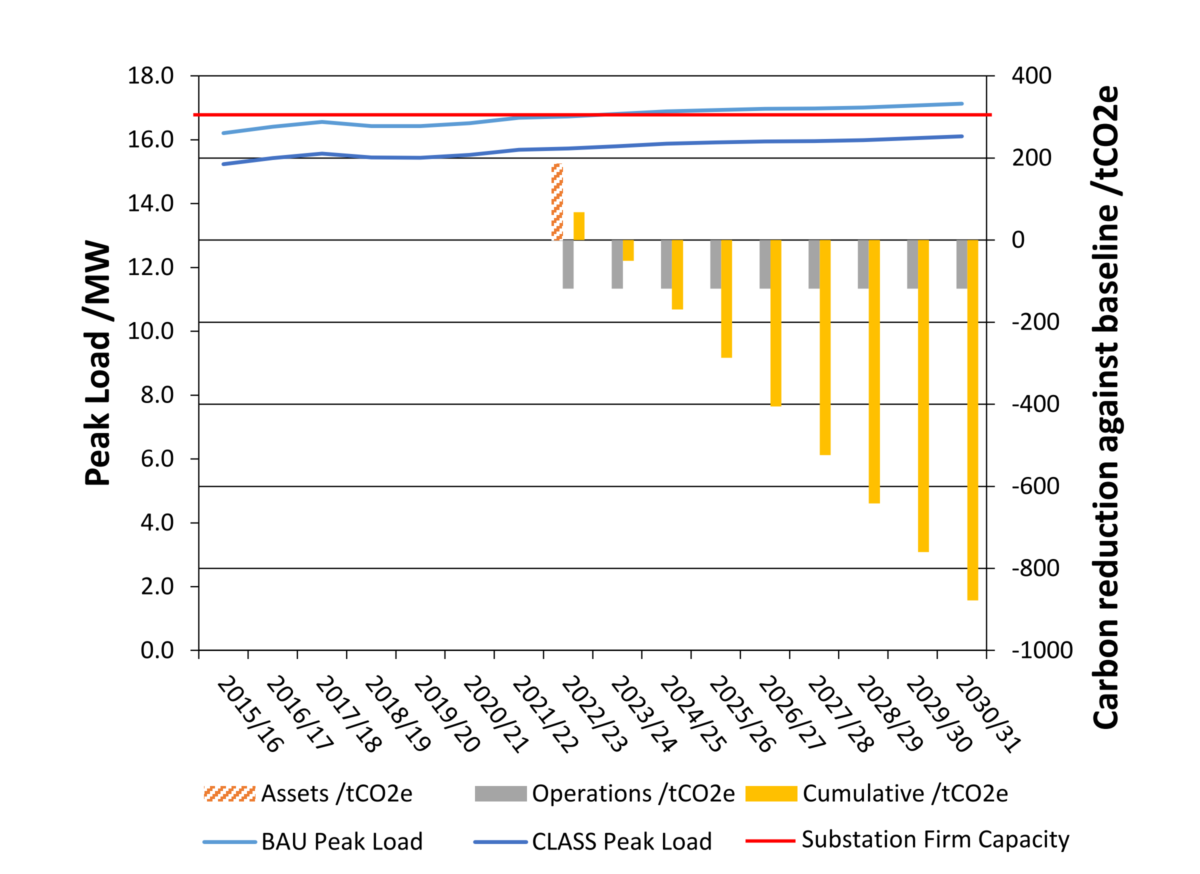


Figure 3 Example Carbon Impact Time Series - Harwood Substation

Carbon Impact	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31
BAU Peak Load	16.2	16.4	16.6	16.4	16.4	16.5	16.7	16.7	16.8	16.9	16.9	17.0	17.0	17.0	17.1	17.1
CLASS Peak Load	15.2	15.4	15.6	15.4	15.4	15.5	15.7	15.7	15.8	15.9	15.9	15.9	16.0	16.0	16.0	16.1
Assets /tCO2e								186								
Operations /tCO2e								-120	-120	-120	-120	-120	-120	-120	-120	-120
Cumulative /tCO2e								66	-54	-175	-295	-415	-535	-656	-776	-896

The potential for asset deferral was identified in up to five of the sixty Trial substations in ED1 and up to fourteen in ED2, deferring up to 2602 tCO2e for 66 substation-years in total according to the load growth scenario examined.

Under the “Focus on Efficiency” scenario, continued load reduction throughout the period 2015 to 2031 means that there is no benefit to the use of the CLASS solution. The greatest benefits were identified in the high-growth “Active Economy” scenario, however, in all cases asset deferral benefits were outweighed by the reduction in losses due to transformer reinforcement under BAU.

Over these time periods the operations impacts were found to be between two and five times greater than asset deferral, highest in the Best View scenario where a small number of substations were able to be deferred for a period of up to eight years each.

Table 3 PDR Carbon Impact CLASS Trial

ED1 (2015-2022)	Years deferred	# Substation Reinforcements Deferred >=3 yrs	Years Deferred >=3 yrs	Net Assets tCO2e	Additional Losses /MWh	Net Operations tCO2e
Active Economy	35	5	24	**927**	-6307	**-2885**
Best View	20	3	19	**558**	-2365	**-1082**
Green Ambition	9	1	8	**186**	-788	**-361**
Focus on Efficiency	4	1	4	**186**	-788	**-361**
ED2 (2023-2031)	**Years deferred**	**# Substation Reinforcements Deferred >=3 yrs**	**Years Deferred >=3 yrs**	**Net Assets tCO2e**	**Additional Losses /MWh**	**Net Operations tCO2e**
Active Economy	73	14	66	**2602**	-17345	**-7935**
Best View	30	4	30	**745**	-7884	**-3607**
Green Ambition	40	3	9	**558**	-2365	**-1082**
Focus on Efficiency	0	0	0	**0**	0	**0**

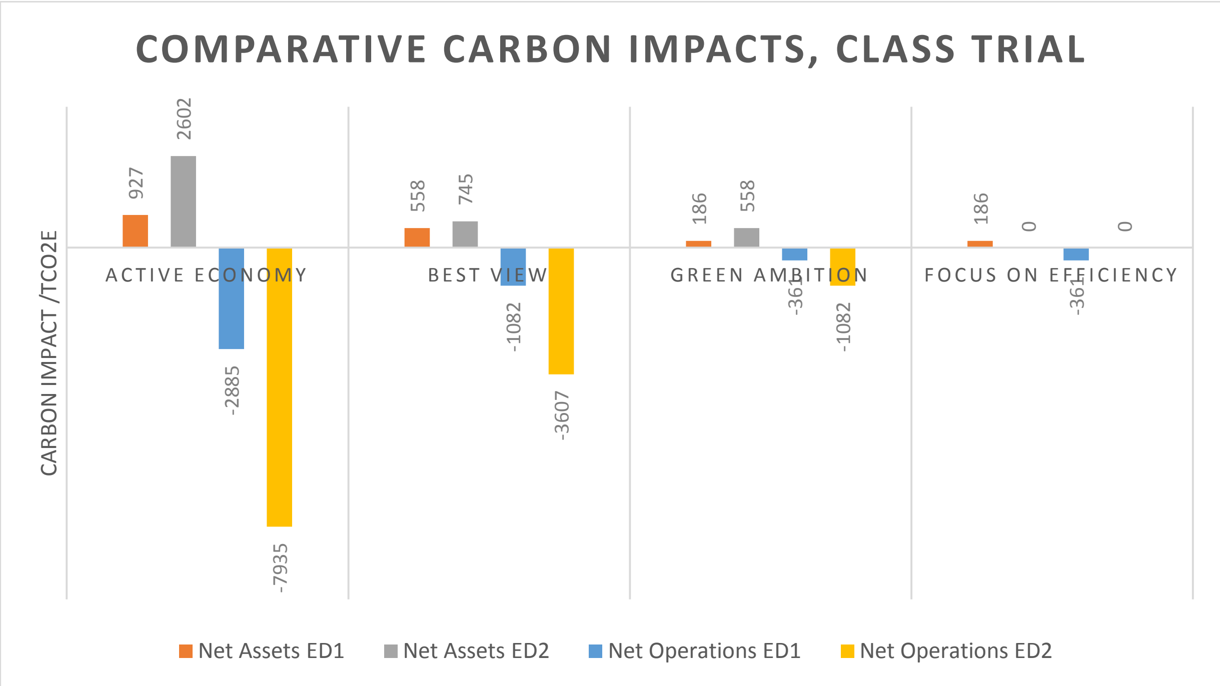


Figure 4 Comparative DR Carbon Impacts

If the 304 suitable substations across the ENW network are considered, similar results are observed. Substantial potential asset deferral is identified, between 558 and 2585 tCO2e in ED1 and up to 6122 in ED2, depending upon the load growth scenario. The operations:asset impact ratio was found to be higher within this larger sample of substations for the “Best View” and “Green Ambition” scenarios.

When scaled to the GB network on a linear basis, the relative benefit of CLASS when load grows quickly is apparent; see for instance Active Economy and Green Ambition during ED2, below. If deferral persists for an extended period of time, as it does in more instances under Best View, then the carbon impact from the absence of the losses improvement accumulates. Deployed in this way, the CLASS solution may tend to increase net emissions.

Table 4 PDR Carbon Impact CLASS deployed at GB Scale

ED1 (2015-2022)	Years deferred	# Substation Reinforcements Deferred >=3 yrs	Years Deferred >=3 yrs	Net Assets tCO2e	Additional Losses /MWh	Net Operations tCO2e
Active Economy	1023	154	781	**28438**	-205247	**-93894**
Best View	649	88	616	**16381**	-161885	**-74057**
Green Ambition	220	33	187	**6143**	-49144	**-22482**
Focus on Efficiency	165	44	165	**8191**	-43362	**-19837**
ED2 (2023-2031)	**Years deferred**	**# Substation Reinforcements Deferred >=3 yrs**	**Years Deferred >=3 yrs**	**Net Assets tCO2e**	**Additional Losses /MWh**	**Net Operations tCO2e**
Active Economy	1870	363	1694	**67344**	-445183	**-203658**
Best View	1001	132	990	**24572**	-260172	**-119021**
Green Ambition	1078	88	264	**16381**	-69379	**-31739**
Focus on Efficiency	22	0	0	**0**	0	**0**

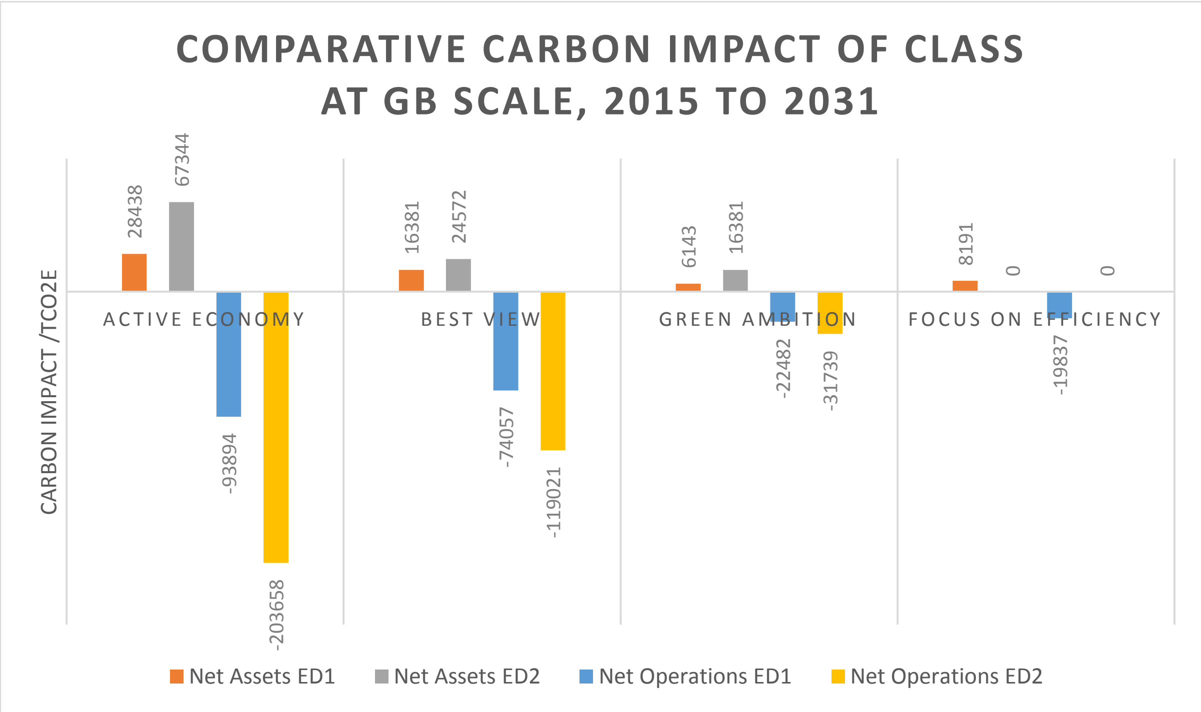


Figure 5 Comparative carbon impact at GB scale

3 Demand Response

Rapid demand response can be used to automatically balance the network by staggering pairs of transformers to reduce voltage available to consumers. When aggregated, voltage control could become relevant to grid scale demand management. Trials 1, 3a and 3b, and UoM Work Package 1 have demonstrated and quantified the coordinated demand response to lowered voltages such that a DNO might provide network balancing to the transmission system operator. This is achieved through rapid isolation of one transformer in a substation pair (Stage 1) or tapping down both (Stage 2) with response times of the order of less than 30s.

During the CLASS trial, the number of frequency deviations that trigger voltage reduction was recorded. Upon activation the service is provided for 30 minutes.

Table 5 Number of CLASS Trial DR trigger events

	Stage 1	***Stage 2***
Month	Frequency event < 49.8 Hz	Frequency event < 49.7 Hz
May-14	11	0
Jun-14	3	0
Jul-14	5	0
Aug-14	2	0
Sep-14	3	0
Oct-14	14	0
Nov-14	21	0
Dec-14	9	0
Jan-15	20	0
Feb-15	8	0
Mar-15	1	0
Apr-15	2	0
Total	99	0

The voltage:demand response relationship is described by the equation (Hasan & Milanovic, 2015):

$$P = P_0 \left(\frac{V}{V_0} \right)^{K_p}$$

The CLASS Trials have identified Kp as between 0.83 and 1.36 according to customer type and season. A 5% reduction in voltage will therefore realise a 4.2% to 6.7% reduction in demand. The same trials have also shown that frequency triggers may occur at any point in time, not just at peak demand, therefore, the scale of service available was calculated at mean demand. For ED2, demand is also modified by the growth under the Best View scenario.

Table 6 Demand Response from application of CLASS across scales

	CLASS Trial		ENW Network Scale		GB Scale	
	ED1	**ED2**	**ED1**	**ED2**	**ED1**	**ED2**
Peak Demand /MW	857	983	3959	4423	43549	48653
Mean Demand /MW	546	626	2522	2817	27741	30992
Demand Reduction Min /MW	22.8	26.1	105	117	1156	1292
Demand Reduction Max /MW	36.8	42.2	170	190	1869	2088

3.1 Asset Carbon Impact

The BAU alternatives to CLASS DR are the balancing services procured by National Grid from thermal plant. It is assumed that there is sufficient capacity in the national balancing markets at present to meet the demand for their respective services over the RIIO ED1 and ED2 periods without new capacity being influenced by the presence or absence of CLASS. For the CLASS case there is a very small asset carbon impact embodied in the autonomous substation controllers, as described in section 2.1, which may provide all CLASS services once installed. As a result, these impacts are regarded as negligible for the DR service.

3.2 Operations Carbon Impact

Operations impacts for the base case are determined as a composite emissions factor multiplied by the scale of the CLASS service potential measured in the trial. This was cross checked against the scale of Primary Response currently held by National Grid to check that total demand for balancing is not exceeded (approx. 2% if CLASS deployed at GB scale). Some degree of the demand reduced by the CLASS intervention may be transferred into a later period of time and met by other marginal plant. As it has not been possible to account for this temporal transfer, the carbon reduction estimates are therefore an upper bound. Max and Min boundaries are estimated from the CLASS trials voltage:demand response measurements.

Table 7 Composite Emissions Factor for Frequency Response Balancing Market

Power Plant Type	Primary Response		Secondary Response	
	/MWh	/tCO2e	/MWh	/tCO2e
CCGT	1987775	824927	1209339	501876
Coal	1296124	1200211	781454	723626
Hydro	49	0	18	0
Oil	286	172	164	98
Pumped Storage	176	108	97	59
Wind	666	0	292	0
Total	3285077	2025417	1991364	1225659
Composite Emissions Factor	tCO2e/MWh	0.62		0.62

The Frequency Response Balancing Market is taken as an example of the type of service that the CLASS DR service may provide an alternative to. Data for Table 5 are taken from National Grid Balancing Market reports, and emissions factors from Hawkes (2010). Further detail is given in the accompanying *Emissions Profiles* report.

The composite emissions factor is applicable at present and for the period of ED1. However, UK coal plant is likely to be phased out before the end of RIIO ED2 due to the European Combustion Plant Directive and its successor environmental regulations. It is therefore assumed that all BAU balancing response is provided by CCGT plant during ED2.

Table 8 Operations Carbon Impact for DR

	CLASS Trial		ENW Network Scale		GB Scale	
	ED1	ED2	ED1	ED2	ED1	ED2
Carbon Impact for CLASS Min /tCO2e p.a.	698	591	3,226	2,659	35,485	29,251
Carbon Impact for CLASS Max /tCO2e p.a.	1,129	955	5,215	4,299	57,366	47,289
Carbon Impact for CLASS Min /tCO2e whole period	5,586	4,728	25,807	21,274	283,878	234,010
Carbon Impact for CLASS Max /tCO2e whole period	9,031	7,643	41,721	34,392	458,928	378,309

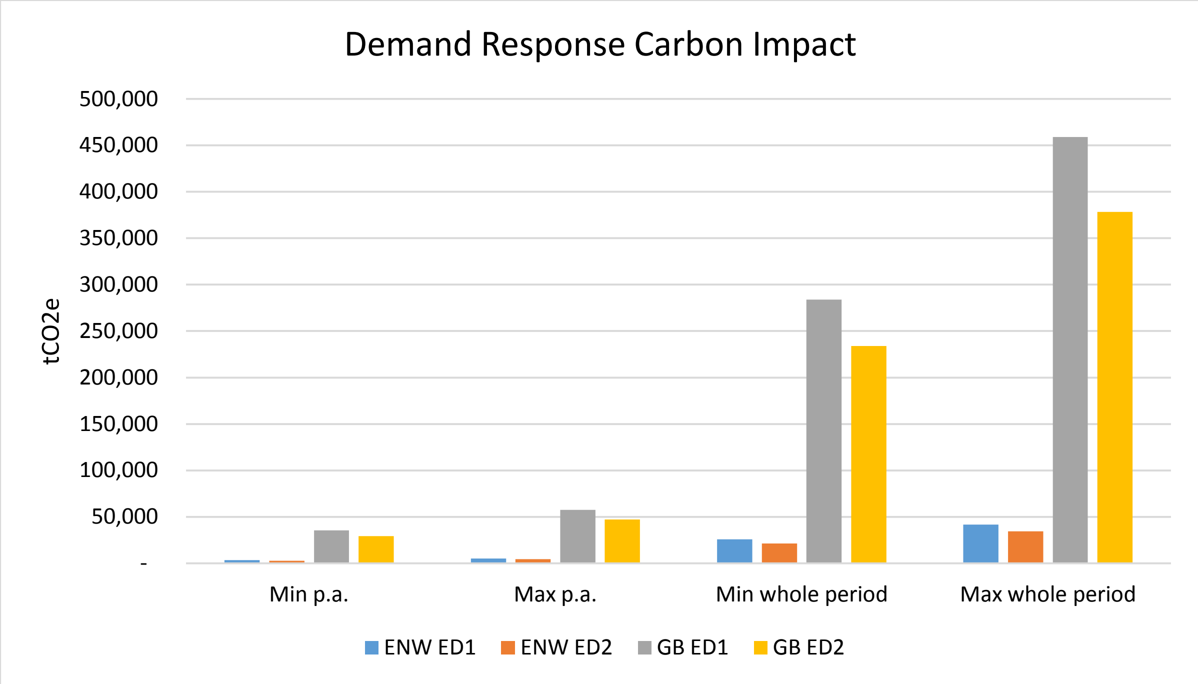


Figure 5 Demand Response Carbon Impact

3.3 Facilitated Carbon Impact

No constraint on LCTs due to balancing that could be uniquely alleviated by CLASS is anticipated in the relevant period. It is assumed that existing fossil backed generation will continue to provide balancing services and that there are negligible geographic or temporal constraints such as with the Peak Demand Response.

4 Reactive Power Absorption

Tap staggering enables CLASS OLTC transformers to generate circulating currents and absorb reactive power. The scale of this capability is explored in Trial 4 and UoM Work Package 2. The most effective and affordable means of delivering additional RP absorption services is taken at present as the installation of static compensators (STATCOMs). For BAU, they are assumed to be newly installed at the same scale as CLASS RP service becomes available and then operated to provide an equivalent reactive power absorption.

4.1 Asset Carbon Impact

STATCOMs are taken to be installed on the network as required and the ABB PCS 6000 12.5MVAr is taken as a representative example. A proxy measure of STATCOM asset carbon impact was developed due to absence of primary examples, building on a recent study (Alaviitalaa and Mattila, 2015; see *Emissions Profile* report for further detail). The total asset carbon per STATCOM unit was estimated as 12 tCO2e.

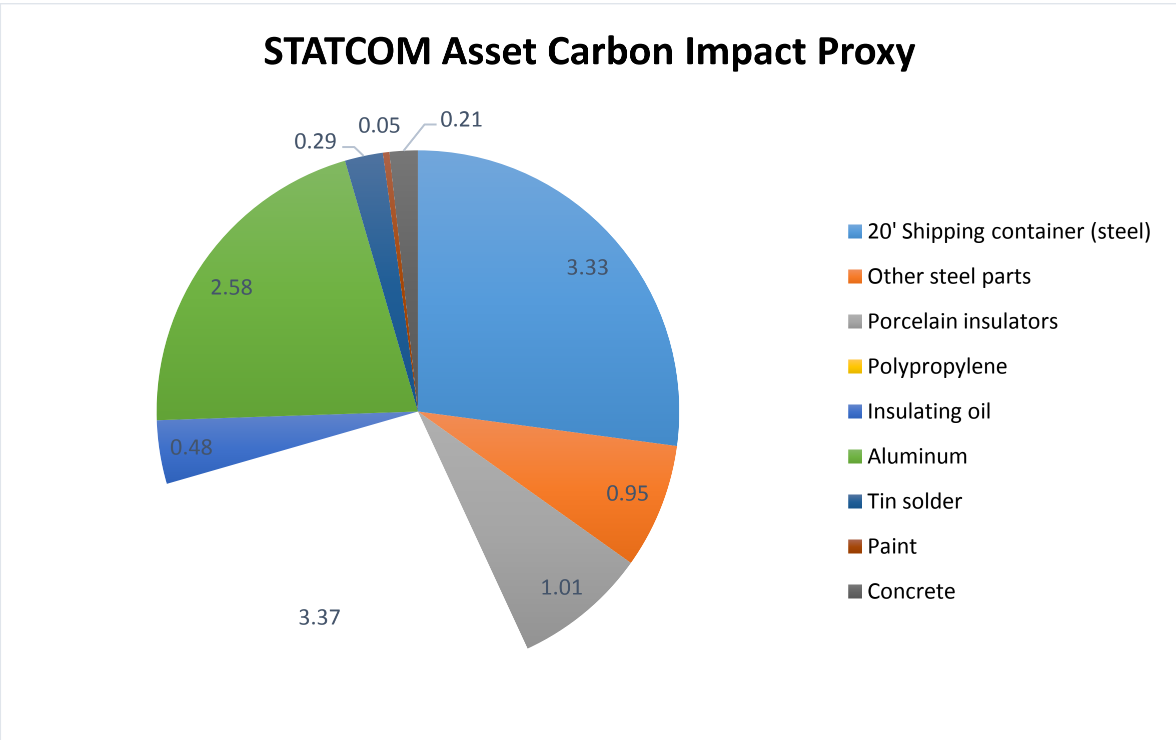


Figure 6 STATCOM Asset Carbon Impact Proxy

The capability of the CLASS RP solution has been modelled in Work Package 2 and the maximum and minimum findings at a 3 tap stagger (+3/-3) are used as the basis for estimating the number of STATCOMs that may be obviated through tap staggering.

Table 9 Asset Carbon Impact for Reactive Power absorption

RP Absorption	Min	Max	
Extra Q absorption capability for the whole ENWL network	129	167	MVAr
Total hours of reactive power absorption (Summer 5 hours per day)	600	600	hours
Extra reactive energy absorption	78	100	GVArh
STATCOMs			
Rating of the ABB PCS 6000 STATCOM	12.5		MVAR
No. of STATCOMS required in ENW network for the equivalent RP absorption	11	14	
Carbon Impact Embodied in STATCOMs	**135**	**172**	**tCO2e**
GB Scale			
Extra Q absorption capability for the whole GB network	1424	1837	MVAr
No. Of STATCOMS required in GB network for the RP absorption	114	147	
Carbon Impact Embodied in STATCOMs	**1400**	**1805**	**tCO2e**

4.2 Operations Carbon Impact

The CLASS RP absorption incurs additional real power losses in the transformers and the network when the transformers are run in a tap staggered arrangement. The range of Q absorption capability was calculated in Work Package 2 and compared to a BAU baseline of STATCOMS continually drawing a small load, 0.75% to 1%, as “hot standby” in order to maintain their availability, with peak consumption during periods of reactive power absorption, of 3% (ABB, 2013). Changes in grid scale power flows were not modelled due to the uncertainty of geographic configuration of the STATCOMs and transformers. The energy savings are converted to tonnes of carbon equivalent at the same grid marginal emissions factor (CCGT) as detailed in section 2.2. This may be an underestimate for the early part of ED1 where coal plant is still contributing to the UK margin but the majority of these facilities are due to be closed or converted to biomass before ED2.

Table 10 RP Operations Carbon Impact breakdown

RP Absorption	Min	Max	
Extra Q absorption capability for the whole ENWL network (Stagger 3)	129	167	MVAr
Total hours of reactive power absorption (Summer 5 hours per day)	600	600	hours
Extra reactive energy absorption	78	100	GVArh
Additional losses	6.4	8.3	MW
Additional losses p.a.	3.8	5	GWh
ENW Network Scale			
Standby power consumption of STATCOMs	0.75%	1.0%	of RP
No. Of STATCOMS required in ENW network for equivalent RP absorption	11	14	
Standby power consumption of STATCOMs p.a.	11	18	GWh
Energy consumption reduction due to CLASS	7.1	13.5	GWh
Emissions intensity of losses	457	457	tCO2e/GWh
Carbon saving due to CLASS p.a.	**3226**	**6188**	**tCO2e**
Carbon saving due to CLASS whole period	**51616**	**99007**	**tCO2e**
GB Scale			
Extra Q absorption capability for the network	1424	1837	MVAr
Extra reactive energy absorption	854	1102	GVArh
No. Of STATCOMS required in ENW network for equivalent RP absorption	114	147	
Energy consumption reduction due to CLASS	71	140	GWh
Carbon saving due to CLASS p.a.	**32316**	**63840**	**tCO2e**
Carbon saving due to CLASS whole period	**517049**	**1021442**	**tCO2e**

The difference between continuous STATCOM power consumption and increased losses due to CLASS “on demand”, presents a substantial reduction in energy consumption and hence carbon impact, up to 6200 tCO2e per annum at the ENW scale.

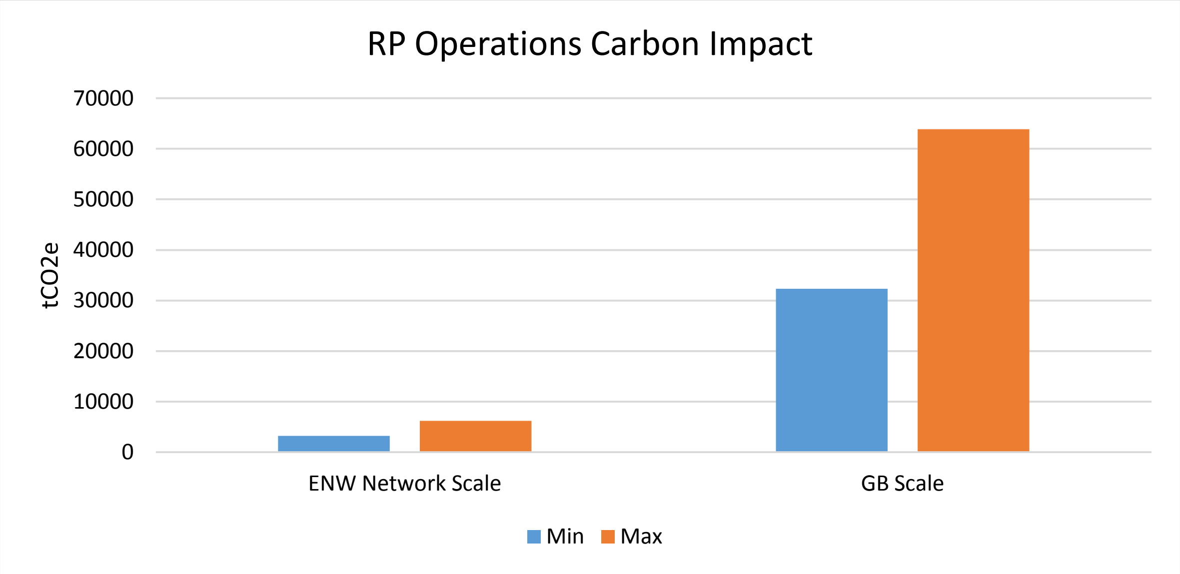


Figure 7 RP Operations Carbon Impact breakdown

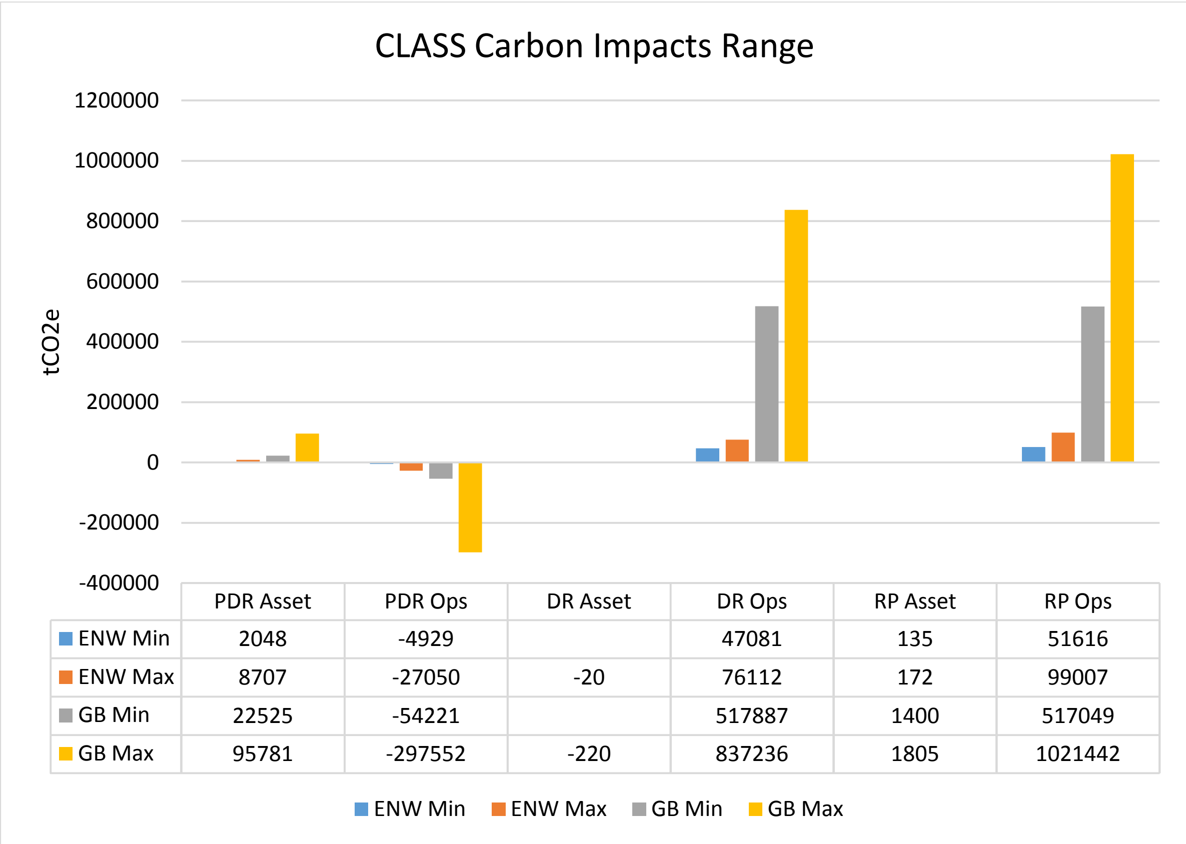
It should be noted that increasing the CLASS RP absorption hours of service does not increase the carbon benefit as the standby consumption of the STATCOMS are assumed to be constant once the reactive power capability is established, whilst CLASS network losses increase to a greater extent than the STATCOM losses during periods of absorption.

4.3 Facilitated Carbon Impact

STATCOMs are substantial power electronics assets, primarily used to facilitate the connection of wind farms. Therefore there may be some benefit from the more rapid deployment of renewable electricity if the CLASS solution proves effective at delivering a proportion of the network's RP absorption needs. However, such an estimate would be highly uncertain given the UK onshore wind policy environment and so no attempt to quantify this potential benefit is justified.

5 Conclusions

There is a substantial range of plausible carbon impacts between the different elements of the CLASS services; the potential benefits in the Demand Response (DR) operations category are over a thousand times greater than the asset impacts of CLASS.



	PDR Asset	PDR Ops	DR Asset	DR Ops	RP Asset	RP Ops
ENW Min	2048	-4929		47081	135	51616
ENW Max	8707	-27050	-20	76112	172	99007
GB Min	22525	-54221		517887	1400	517049
GB Max	95781	-297552	-220	837236	1805	1021442

Figure 8 Summary of CLASS Carbon Impacts range and comparison

The operations carbon impacts dominate, outweighing assets for every service. Although there are very small asset impacts associated with the delivery of the CLASS services, the potential for permanent deferral of assets is limited.

Some aspects of the carbon impact of CLASS are sensitive to future circumstances and conditions. As such a scenarios approach was adopted to investigate the scale, magnitude and direction of each of the carbon impacts under different plausible assumptions of the future. The greatest value of Peak Demand Reduction (PDR) to the network would most likely be realised under the Best View scenario where potential for deferral is greatest. However, in these circumstances the carbon impact from the absence of the losses improvement, due to costly BAU reinforcement, accumulates. Deployed in this way, the CLASS solution may tend to increase net emissions if the grid margin is provided by gas power stations (CCGTs) as is likely over the RIIO ED1 and ED2 periods. This effect would be expected to diminish in the long term as the marginal emissions intensity of the UK grid reduces due to low carbon sources dominating generation whilst being matched with bulk energy storage technologies.

CLASS could reduce the carbon impact of demand response (DR) and reactive power (RP) provision substantially, if energy demand reduction is realised in addition to power reduction. It is the continuous operations impacts category that provides the dominant DR and RP carbon benefit, rather than the asset deployment reduced or deferred. On a national scale, the total benefits from both the DR and RP ancillary services could be as much as 116,000 tCO_2e per annum. Were very high quantities of renewable generation and grid scale energy storage to become available then the benefits of CLASS may be reduced as the marginal emissions factor is reduced.

Finally, it is difficult to make a strong and substantiated case for facilitated carbon impacts from the CLASS services. Regardless of this issue, the provisional quantification for restricted cases, suggests the potential benefits are very small.

This further example of carbon accounting for distribution network infrastructure will contribute to the academic body of knowledge in an under-researched area.

6 Acknowledgements

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