FuturoFirma
Sustainability Consulting

Final Report

Life-Cycle Carbon Impact Assessment of the *Respond* project

Document History

Project name	Life-Cycle Carbon Impact Assessment of the *Respond* project
Author	Dr Herb Castillo (herb.castillo@futurofirma.com)

Version	Issue Date	Status	Issuer	Comments
d0.1	27th June 2018	*Draft*	Dr Herb Castillo	*1st Draft issued for review by ENW*
1.0	18th July 2018	*Final*	Dr Herb Castillo	*Final report incorporating comments from ENW*

Executive Summary

Introduction

The increasing amounts of distributed generation and the corresponding increase in fault levels poses significant challenges to operation of the electricity distribution network.

To mitigate these risks, the Respond project is trialling a Fault Level Assessment Tool (FLAT) which calculates potential fault current in near real time, and then utilises one of the three innovative techniques shown below, to manage fault current safely.

Adaptive Protection	• Also known as sequential tripping, this technique involves changing the sequence of operation of protection and circuit breaker switching, such that the potential fault current is managed
I_S-Limiter	• A technology used globally (but not currently in the UK) that can quickly detect rapid rise in current when a fault occurs and respond to break the current
Fault Current Limiting (FCL) Service	• Entering into commercial agreements with customers to operarate equipment so as to offer fault level management services to DNOs.

One of the fundamental hypotheses underpinning Respond is that implementation of the Respond techniques to manage fault levels can extend the useful life of existing assets. This potential to extend the useful life of existing assets in turn presents opportunities for reduced carbon impact.

Accordingly, this report summarises the outcomes of a Life Cycle Assessment (LCA) that was undertaken to assess the carbon impact of Respond techniques relative to traditional approaches for managing increasing fault levels on the network.

Carbon impact of Respond at site level

To enable comparison of Respond's carbon impact to the traditional approach for managing increasing fault levels on the network, the carbon impact of the traditional approach was calculated. This showed life-cycle emissions of 51,088 kg CO_2e for the traditional approach at each site where switchgear and associated cables are replaced.

The carbon impact of network-level Respond techniques were then assessed. This estimated the life cycle emissions arising from installation of an I_S-Limiter at 30,921 kg CO_2e, and Adaptive Protection at 829 kg CO_2e.

As shown in the table below, carbon savings of 20,167 kg CO_2e and 50,259 kg CO_2e arise from each installation of an I_S Limiter and Adaptive Protection respectively, *vis-à-vis* traditional DNO interventions for addressing increasing fault levels on the electricity distribution network.

Respond Technique	Carbon impact of Respond (kg CO_2e)	Carbon impact of Traditional approach (kg CO_2e)	Carbon impact of Respond Technique relative to Traditional approach (kg CO_2e)
I_S-Limiter	30,921	51,088	-20,167
Adaptive Protection	829	51,088	-50,259

It should be noted that the table above excludes emissions of 1.448 kg CO_2e that are incurred each time the I_S-Limiter's inserts are transported to Germany for refurbishment after a fault event. However, these emissions are included in the extrapolation (below) of carbon impacts across the DNO area and GB, where a specified number of fault events is assumed. (See section 3.6.1 of the report for a more detailed discussion of this.)

Extrapolation to Electricity North West's DNO area

To enable calculation of Respond's carbon impact at the DNO level, a deployment split between Adaptive Protection and I_S-Limiters of 80:20 is assumed, i.e., 80% Adaptive Protection and 20% I_S-Limiters. The emissions arising from transportation of the I_S-Limiter's inserts to Germany for refurbishment after each fault event, are also considered in this assessment.

The analyses showed that if deployed across ENW's DNO area, Respond has the potential to save 542,926 kg CO_2e per year relative to traditional methods for managing increasing fault levels on the network. This is summarised in the table below.

Respond Technique	Comparative carbon impact per installation (kg CO_2e)	No. of installations per year	Gross Carbon impact (kg CO_2e)	Transport of inserts (kg CO_2e)	Net Carbon impact across DNO area (kg CO_2e /year)
I_S-Limiter	-20,167	2	-40,334	2.90	-40,331
Adaptive Protection	-50,259	10	-502,594	0	-502,594
Total potential carbon impact per year across DNO area *relative* to traditional approaches for managing increasing fault levels			-542,928	2.90	**-542,926**

Extrapolation to GB distribution network

Assuming the 80:20 split for the deployment of Adaptive protection and I_S-Limiters, the analyses shows potential for Respond to save 7,432,431 kg CO_2e per year, if deployed across the 14 DNO licence areas in Great Britain.

Respond Technique	Comparative carbon impact per installation (kg CO2e)	No. of installations per year	Gross Carbon impact (kg CO_2e)	Transport of inserts (kg CO_2e)	Net Carbon impact across GB (kg CO2e /year)
I_S-Limiter	-20,167	34	-677,611	49.23	-677,562
Adaptive Protection	-50,259	134	-6,754,869	0	-6,754,869
Total potential carbon impact per year across GB *relative* to traditional approaches for managing increasing fault levels			-7,432,480	49.23	-7,432,431

Carbon impacts of the FCL service

Details of the FCL equipment provided in the *Fault Current Limiting Service Equipment Specifications and Installation Report* enabled calculation of the carbon impact of the FCL service. This estimated the gross carbon impact of the FCL service at 1071 kg CO_2e per installation, as shown below.

FCL Equipment	Gross Carbon impact (Kg CO_2e)
Adaptive Protection	829
RTU (including battery)	242
Total	**1071**

It will be noted from the table above that a comparison to traditional approaches for managing fault-levels was not undertaken. This is because the Respond trial did not ascertain how deploying FCL at customer premises might affect the useful life of network assets.

Summary

The LCA of Respond’s carbon impact shows that relative to traditional approaches, both the I_S-Limiter and Adaptive Protection provide opportunities for reducing the carbon emissions associated with management of fault levels on the electricity distribution network.

It should also be noted that even without considering the potential benefits of the FCL service on network assets’ useful life, the estimated gross carbon impacts of the FCL service are nominal.

Contents

FuturoFirma
Sustainability Consulting

Abbreviations and Glossary

Acronym	Definition
BAU	Business As Usual
CO_2e	Carbon Dioxide equivalent
DNO	Distribution Network Operator
ENW	Electricity North West
FCL	Fault Current Limiting
GB	Great Britain
HV	High Voltage
kg	Kilogrammes
kWh	Kilowatt Hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LV	Low Voltage

1 Introduction

1.1 Purpose of this report

Since 2015, Electricity North West (ENW) has been undertaking the innovative Respond project, funded via Ofgem's Network Innovation Competition (NIC) mechanism.

FuturoFirma Sustainability Consulting have been commissioned by ENW to undertake an assessment of the Carbon impact of Respond *vis-à-vis* traditional approaches for managing fault levels on the HV and EHV Distribution network. *(In this context 'Carbon' is an umbrella term for the suite of gases that contribute to the greenhouse effect, and should be interpreted as such throughout this report.)*

This document is the final report of the Carbon Impact Assessment Work Package for Respond, and presents the final results from the analyses. It should be read in conjunction with the Interim Carbon Impact Assessment Report[1] published in March 2018, which set out the methodology and approach for undertaking the carbon assessment.

1.2 The Respond Project

The increasing amounts of distributed generation and the corresponding increase in fault levels poses significant challenges to operation of the electricity distribution network.

To mitigate these risks, the Respond project is trialling a Fault Level Assessment Tool (FLAT) which calculates potential fault current in near real time and then utilises one of the three innovative techniques shown in Figure 1 below, to manage fault current safely.

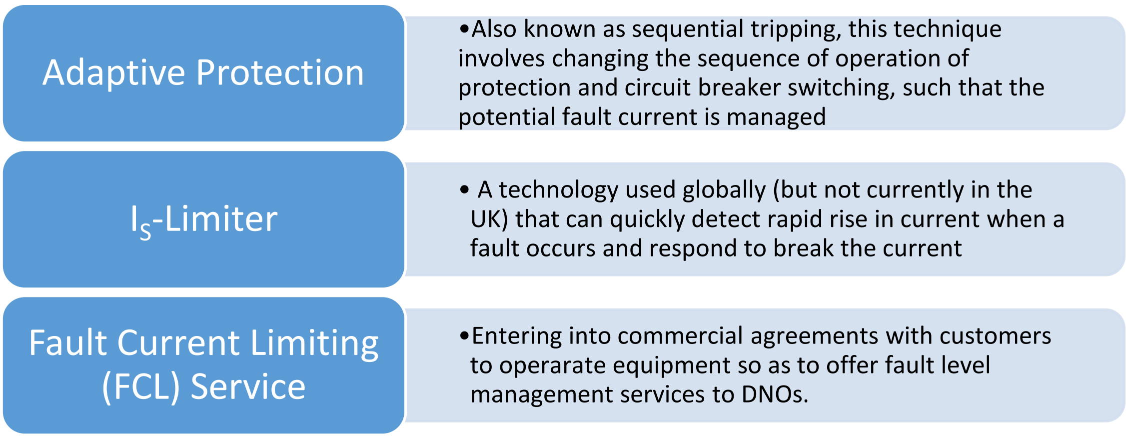

Figure 1: The three Respond techniques

[1] https://www.enwl.co.uk/globalassets/innovation/respond/respond-key-documents/carbon-impact-assessment-interim-report.pdf

1.3 The potential for Respond to have Carbon impacts

One of the fundamental hypotheses underpinning the Respond project is that implementation of the Respond techniques to manage fault levels can extend the useful life of key network assets and defer network reinforcement.

In this regard, Respond presents potential for carbon savings relative to the traditional approaches for managing fault levels.

However, Respond will also have some carbon impacts/penalties associated with the techniques. For example, there will be embodied carbon in the Respond equipment, e.g., the I_S-Limiter and the concrete used in construction, etc.

Estimation of the overall carbon impact of the Respond techniques *vis-à-vis* traditional approaches, will therefore require comparison of Respond's net carbon impacts to the carbon impacts of traditional approaches for managing fault levels on the network.

1.4 Structure of this report

The remainder report is set out as follows.

Section 2:	Sets out the methodology for undertaking the carbon impact assessment
Section 3:	Provides a comparative assessment of the carbon impact of the I_S-Limiter and Adaptive Protection relative to traditional approaches for managing fault levels
Section 4:	Sets out the carbon impact of the Fault Current Limiting (FCL) Service
Section 5:	Provides conclusions and a summary of the analyses and findings

FuturoFirma
Sustainability Consulting

2 Methodology

A Life Cycle Assessment (LCA) approach – in accordance with ISO 14044, was applied for undertaking the carbon assessment. In brief, LCA assesses carbon emissions throughout an asset life cycle, i.e., from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal.

ISO 14044 specifies requirements and provides guidelines for undertaking a life cycle assessment (LCA). The key stages include: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

2.1 Goal definition and scope

The goal of this assessment is to assess the life-cycle carbon impact of Respond techniques relative to traditional approaches for managing fault levels. This comparative analysis was undertaken with the I_S-Limiter and Adaptive Protection specifically. (As explained in subsequent sections, whilst the gross carbon impact of the FCL service was estimated, this was not compared to traditional approaches.)

As with previous carbon assessments for ENW innovation projects, the *Disposal* phase of the product life cycle was excluded (See for example Jones 2018). The *Disposal* phase is often excluded in LCA where it is assumed that this phase has minimal impact (Fthenakis *et al*, 2011).

All other stages of the life cycle are considered.

The key assessment was undertaken at a site level. To show the potential carbon impacts of Respond at wider scale however, extrapolation techniques were used to derive an estimate of Respond carbon impacts at DNO and GB distribution network levels.

2.2 Embodied emissions in network assets

As a significant proportion of the carbon impacts from the traditional and Respond's approach to managing faults (positive and negative) will emanate from the network assets, the concept of 'embodied' emissions is highly relevant.

In simplest terms, embodied emissions refer to the carbon emitted to extract, refine, process, transport and fabricate a material or product. To calculate embodied carbon, it is often necessary to collate a Life Cycle Inventory (LCI) – which quantifies the material and energy flows of the asset.

As part of this assessment, the LCI for some assets had to be developed from scratch (as no previous LCI had been developed for them). In some cases, it was possible to draw on previous work, including outputs from past ENW innovation projects such as the Smart Street project, to derive LCIs or calculations of embodied carbon for some network assets. (See section 2.3 below for a more detailed discussion of this.)

2.3 Emission Sources

This section builds section on 2.2 above by setting out – more specifically, some of the assets and activities that will either provide a carbon saving or a carbon penalty. These sources are summarised in Table 1 below.

Table 1: Sources of carbon savings and carbon penalties

Sources of carbon emissions or/and carbon savings	
Network Assets	
Switchgear	Respond has potential to extend the useful life of switchgear, thus (potentially) reducing its whole life impact by delaying replacement of the asset.
Cable	Replacement of switchgear would typically also necessitate the replacement of a total of 1km of HV cable. Therefore, if Respond extends the life of switchgear, then the need to replace cable is also negated, which could provide a carbon saving.
Respond Equipment	
I_S-Limiter	The I_S-Limiter and its enclosure, will have embodied carbon, thus representing a carbon penalty for Respond. There are also carbon impacts arising from its maintenance; specifically the need to transport inserts to Germany for refurbishment, after every fault event.
Adaptive Protection	The Adaptive Protection Relay will only have some embodied carbon, representing a potential carbon penalty for Respond.
Enabling works	
Civil Works	By extending the useful life of existing assets, and thus negating the need for civil works that would have been required to install new assets, Respond will provide a carbon benefit. However, as the I_S-Limiter is mounted on concrete plinths, the embodied carbon in the concrete is a carbon penalty for Respond.

2.4 Calculating the net carbon impact of Respond interventions

In simplest terms, the net carbon impact of Respond is the difference between the carbon impact of the traditional approach for managing fault levels on the network and the carbon impact of the Respond intervention.

This is summarised in the following equation:

$$CI = \sum_{y=0}^{n} TA_{CI} - R_{CI}$$

Where:

CI is the comparative carbon impact of applying the Respond interventions

TA_{CI} is the carbon emissions from Traditional approach to managing faults

R_{CI} is the carbon emissions managing faults using the Respond approaches

2.5 Data Sources

A key challenge for developing an LCI and undertaking an LCA is typically the lack of data on embodied carbon or/and the carbon impact of assets and processes. To mitigate these challenges, this assessment drew on a diverse range sources of data and proxies. These are summarised in Table 2 below and are discussed further in section 3 of this report.

Table 2: Data sources for inputs into calculations

Carbon data required	Data Source
Embodied carbon in Network Assets, e.g., including Switchgear and Cables	• Environmental Product Declaration by Manufacturers • Previous ENW LCN and NIC projects • Peer reviewed Research publications
Embodied carbon in Respond Assets, e.g., the I_S-Limiter	• Bottom-up analyses undertaken as part of this project • Environmental Product Declaration by Manufacturers • Peer reviewed Research publications
Civil Works	• Bottom-up analyses undertaken as part of this project • Previous ENW LCN and NIC projects • Peer reviewed Research publications

3 Results

This section presents the results of the analyses. The net carbon impact of I_S-Limiter and Adaptive protection are calculated and compared to the impacts of traditional approaches for managing faults levels on the network.

The carbon impacts of the FCL service is treated separately to the other two Respond techniques. In particular, whilst the embodied carbon in the FCL equipment is calculated, the carbon impact is not compared to a traditional approach *per se*. This is because the Respond trial did not ascertain how deploying FCL at customer premises might affect the useful life of network assets.

3.1 Carbon Impact of IS- Limiter installation

Given the relative novelty of I_S-Limiters, LCI data had not been previously collated. Therefore, a bottom-up approach was employed as part of this project to collate the required data to calculate the embodied carbon arising from I_S-Limiter installation.

To enable this, the manufacturers (ABB) were contacted, who provided an estimate of the materials used in manufacture of the I_S-Limiters. GHG emission factors were then applied to calculate embodied carbon from the material mass. Table 3 shows the carbon embodied in the materials used for the I_S-Limiter

Table 3: Carbon arising from materials for I_S-Limiter

Material	Amount (kg)	Emission Factors	kg CO_2e
Copper	110	3.30E+00	361
Epoxy Resin	46	8.07E+00	367
Aluminium alloy	545	8.20E+00	4465
Sheet Steel	161	2.30E+00	369
Subtotal	**860**		**5563**

Table 4 shows the carbon arising from the electricity consumed during manufacture of the I_S-Limiter

Table 4: Electricity consumed during production of I_S-Limiter

Energy Source	kWh	Emission Factor	kg CO_2e
Electricity	130	0.5	65
Subtotal	130		**65**

For the deployment in Respond, I_S-Limiters are housed in a stainless steel enclosure. Therefore, the embodied carbon in that enclosure also had to be calculated. It is estimated that 15 stainless steel metal sheets are used for fabrication of the enclosure.

Table 5: Embodied carbon in the I_S-Limiter's stainless steel enclosure

I_S-Limiter Enclosure	kg	Emission Factor	kg CO_2e
15 x Sheet metal (Stainless Steel) (1.71m * 1m * 0.006m)	1208	6.80E+00	8215
Subtotal	**1208**		**8215**

The enclosure is secured and mounted on concrete plinths, and therefore, the embodied carbon in the concrete is also considered.

There are a range of Emission factors quoted in the literature for the embodied carbon in concrete. For this assessment, the higher end of this range is used, i.e., 300 kg CO_2e per cubic metre (m^3) of concrete (see Marceau *et al*, 2007). Using this emission factor, the embodied carbon in the concrete plinth for the I_S-Limiter is estimated at 11,559 kg CO_2e.

Table 6: Embodied carbon in concrete plinth on which I_S-Limiter is mounted

Concrete plinth for I_S-Limiter	m^3	Emission Factor	kg CO_2e
Concrete	38.53	3.00E+02	11,559
Subtotal	**38.53**		**11,559**

The IS-limiter container also houses the I_S-limiter series circuit breaker (CB), the purpose of which is to disconnect all three 11kV phases of the T13 transformer in the event that any of the I_S-limiter fuses operate to prevent single or dual phasing from occurring.

As a proxy, it is assumed that the life cycle emissions of the series CB is half (50%) of the I_S-Limiter unit, i.e., 50% of the emissions arising from the material used and electricity consumed during manufacture of the I_S-Limiter.

Table 7: Assumed carbon impact of the I_S-Limiter series circuit breaker (CB)

Emission source	Assumed carbon impact (kg CO_2e)
Materials used in manufacture	2781
Electricity used in manufacture	32.5
Total	**2814**

Furthermore, the installation of the I_S-Limiter involves the connection of a total of 0.1 meters of cable. Therefore the embodied carbon in the cables are also considered.

As discussed in section 3.3.2 (below), the embodied carbon in HV cables used by ENW is estimated at 27,058 kg CO_2e per kilometre of cable.

Therefore, the embodied carbon in 0.1 km of cable connected during I_S-Limiter installation is estimated at 2706 kg CO_2e.

3.1.1 Total estimated carbon impact of I_S-Limiter Installation

The total carbon impact of the I_S-Limiter installation is the sum of the embodied carbon in the various activities and material involved in its manufacture and installation. As shown in Table 8 below, this is estimated to be **30,921 kg CO_2e per I_S-Limiter installation.**

Table 8: Estimated carbon impact of a single I_S-Limiter installation

IS-Limiter installation components	kg CO_2e
Material used to manufacture the I_S-Limiter	5,563
Electricity used in manufacture of I_S-Limiter	65
IS-Limiter's stainless steel enclosure	8,215
Concrete plinth on which I_S-Limiter is mounted	11,559
I_S-Limiter series circuit breaker (CB)	2,814
Cables connected during installation of I_S-Limiter	2,706
Total I_S-Limiter carbon impact (per installation)	**30,921**

3.2 Carbon Impact of Adaptive Protection

ABB had previously developed an LCI for Protection Relays, specifically the SPACOM 100 series[2] as per Tables 9 and 10 below, and had estimated the embodied carbon to be circa 829 kg CO_2e. That value is accordingly used in these analyses as an estimate of the carbon impact of the adaptive protection technique.

Table 9: Declared carbon impact of Protection Relay by ABB

Stage	kg CO_2e
Manufacturing Stage	130
Usage phase	699
Total	**829**

The LCI used by ABB to derive the carbon values above is shown in Table 10 below.

Table 10: LCI for calculating the carbon impact of the Protection relay

Material	Manufacturing (kg)	Use (kg)	Total (kg)
Bauxite	4.10	0.06	4.16
Copper	0.30	0.01	0.31
Crude oil	13.75	29.64	43.39
Hard coal	24.50	292.78	317.28
Iron in ore	1.54	2.01	3.55
Lignite	16.94	3.81	20.75
Limestone	0.92	4.28	5.20
Natural gas	8.58	29.08	37.66
Uranium in ore	0.00	0.01	0.01

Using the ABB figures, total embodied carbon of Adaptive Protection is therefore deemed to be: 829 kg CO_2e

3.3 Carbon impacts of the *traditional* approach for managing faults

For the purpose of this analyses, it is assumed that in current Business-As-Usual (BAU), when fault levels are deemed to be approaching switchgear fault ratings, the switchgear is replaced. It is also assumed that the replacement of switchgear always involves the replacement of a total of 1 km of cable, i.e., 0.1 km x 10 cables.

Therefore, the carbon impact of the traditional approach for managing faults primarily consists of the carbon impacts of Switchgear replacement and the carbon impacts of replacing 1 km of cable per switchgear. (Estimates of these are provided in the subsections below.)

[2] ABB _ Environmental Product Declaration - Protective Relays SPACOM 100 series (https://library.e.abb.com/public/025bfbe89b83539ec2256d98002e0399/SPA100EPD_ENa.pdf)

3.3.1 Carbon impact of Switchgear

As part of ENW's Smart Street project, an LCA was undertaken to estimate the carbon impact of a Lucy VRN2a LV Switchgear (Jones, 2018). This estimated the embodied carbon at 2,403 kg CO_2e as shown in Table 11 below.

Table 11: Cradle to site life cycle GHG emissions for switchgear

Material	Embodied carbon (kg CO_2e)
Energy	852
Electronics	746
Steel	469
Epoxy Resin	198
Copper	64
Aluminium	57
PVC	13
Transport	4
Total	**2,403**

For the purposes of this assessment, the values from the Smart Street project had to be extrapolated to reflect the switchgear used at the Primary substations, which typically comprises of ten panels, as opposed to one panel. Accordingly, the estimate derived in the Smart Street project is multiplied by 10 to obtain an estimate for switchgear at a Primary substation.

Therefore, the embodied carbon in a Switchgear that would be replaced in the traditional interventions for responding to increasing fault levels, is estimated 24,030 kg CO_2e.

3.3.2 Carbon emissions arising from cable replacement

To estimate the carbon impact of HV cables, a bottom-up assessment was undertaken of the carbon impact of the 300 mm^2 triplex aluminium HV cable used by ENW. This was based on data provided by ENW stakeholders.

As per Table 12 below, the embodied carbon of the 300 mm^2 triplex aluminium cable is estimated at 27,058 kg CO_2e for 1 km of cable.

Table 12: Carbon impact of 1km cable replacement

Material	kg	Emission factor	Kg CO_2e
Aluminium	2,430	8.20E+00	19,926
XLPE	925	1.86E+00	1,721
Copper	941	3.30E+00	3,105
MPDE	901	2.56E+00	2,307
Total	**5,197**		**27,058**

3.3.3 Total carbon impact of the traditional approach for managing fault levels

As stated above, the carbon impact of the traditional approach for managing fault levels primarily arises from the carbon impacts of Switchgear replacement and the carbon impacts of replacing 1 km of cable.

Accordingly, the carbon impact of Business as Usual approaches for managing increasing fault levels on the network is estimated as follows:

Table 13: Total carbon impact of the traditional approach for managing fault levels

Activity in traditional approach	kg CO_2e
Switchgear Replacement	24,030
1 km cable replacement	27,058
Total	**51,088**

As per the table above, the total carbon impact of the BAU approach for managing fault levels on the network is calculated as 51,088 kg CO_2e for switchgear and cable replacement.

3.4 Comparative carbon impact of utilising an I_S-Limiter relative to traditional approaches for managing fault levels

The net carbon impact of a Respond technique at a site is calculated by subtracting the carbon impact of the Respond technique from the carbon impact of the traditional approach.

In the case of the I_S-Limiter, the net carbon impact is estimated as per Table 14 below. (Refer to subsections above for detail of how the various inputs into the calculations have been derived.)

Table 14: Carbon impact of I_S-Limiter relative to BAU approach

I_S-Limiter Carbon Savings	kg CO_2e
I_S-Limiter carbon impact	30,921
Traditional BAU carbon impact	
- *Switchgear Replacement*	24,030
- *Cables*	27,058
Net Carbon Impact of I_S-Limiter relative to traditional approach to managing fault levels	**-20,167**

As shown, where an I_S-Limiter is deployed as opposed to replacing the switchgear, it is estimated that up to 20,167 kg CO_2e can be saved per affected site[3].

Deployment of an I_S-Limiter to address increasing fault levels, as opposed to employing traditional approaches, therefore provides carbon benefits.

[3] It should be noted that the table above excludes emissions of 1.448 kg CO_2e that are incurred each time the I_S-Limiter's inserts are transported to Germany for refurbishment after a fault event. However, these emissions are included in the extrapolation (below) of carbon impacts across the DNO area and GB, where a specified number of fault events is assumed. (See section 3.6.1 of the report for a more detailed discussion of this.)

3.5 Comparative carbon impact of Adaptive Protection relative to traditional approaches for managing fault levels

In the case of Adaptive Protection, the net carbon impact relative to BAU approaches is as per Table 15 below. (Refer to subsections above for detail of how the various inputs into the calculations have been derived.)

Table 15: Carbon impact of Adaptive Protection relative to traditional approach

Adaptive Protection Carbon Savings	Kg CO_2e
Adaptive Protection carbon impact	829
Traditional BAU	
- *Switchgear Replacement*	24,030
- *Cables*	27,058
Net Carbon Impact of Adaptive Protection relative to traditional approach to managing fault levels	**-50,259**

As shown, where Adaptive Protection is deployed as opposed to replacing the switchgear and cables, it is estimated that up to 50,259 kg CO_2e can be saved per affected site.

Deployment of Adaptive Protection to address increasing fault levels, as opposed to employing traditional approaches, therefore provides carbon benefits.

3.6 Extrapolation of Respond's carbon savings to the DNO area

ENW proactively monitors fault levels to identify areas where fault levels may be increasing and may be approaching the fault-level rating of the associated switch gear. The number of identified sites with fault-level issues varies year-on-year; but discussions with ENW stakeholders suggest that on average, approximately 12 sites are identified per year where intervention to deal with increasing fault levels is taken.

In this section of the report, estimates are derived of the carbon emissions that would arise if Respond techniques were used to manage these identified increasing fault level issues, as opposed to traditional interventions.

For the purposes of these analyses and based on conversations with the Respond project team, the deployment split between the Adaptive Protection and I_S-Limiters is assumed to be 80:20, i.e., 80% Adaptive Protection and 20% I_S-Limiters.

Therefore, if these assumptions are applied and if Respond techniques were deployed at sites with fault level issues in ENW's DNO area, the split of the two Respond techniques at network level would be as shown in Table 16 below.

Table 16: Assumed split of Respond techniques (per year) if deployed to ENW's DNO area

Respond Technique	Number of sites
I_S-Limiter	10
Adaptive Protection	2

3.6.1 Carbon impact of transporting I_S-Limiter's inserts to Germany

It should be noted that when there is a fault event – and the I_S-Limiter is accordingly activated, the I_S-Limiter's insert has to be replaced and the activated insert sent to Germany for refurbishment.

Therefore, carbon emissions arise from the transportation of the inserts to Ratingen, Germany for refurbishment. To assess the carbon impact of deploying I_S-Limiters across the DNO area, this carbon impact accordingly has to be calculated.

As shown in Table 17 below, the transport of an insert results in the emission of 1.448 kg CO_2e.

Table 17: Carbon impact of transporting insert for refurbishment

Distance (km) Manchester to Ratingen, Germany	Weight of insert (tonne)	Total tonne-kilometres	Emission Factor	Carbon impact of transporting an insert (kg CO_2e)
905	0.02	18.1	0.08	**1.448**

In the assumed deployment split across ENW's DNO area, IS-Limiters would be deployed twice per year, resulting in total carbon impact of **2.90 kg CO_2e** per year arising from the transportation of the inserts to Germany.

3.6.2 Estimated carbon savings from deploying Respond in ENW's DNO area

Applying the split shown previously in Table 16 above, and comparing the carbon impact of the Respond techniques to the carbon impact of traditional approaches for dealing with increasing fault levels, shows that Respond techniques have the potential to save **542,926 kg CO_2e per year** across ENW's DNO area (see Table 18 for details).

Table 18: Potential Respond carbon savings across ENW's DNO area

Respond Technique	Comparative carbon impact per installation (kg CO_2e)	No. of installations per year	Gross Carbon impact (kg CO_2e)	Transport of inserts (kg CO_2e)	Net Carbon impact across DNO area (kg CO_2e /year)
I_S-Limiter	-20,167	2	-40,334	2.90	-40,331
Adaptive Protection	-50,259	10	-502,594	0	-502,594
Total potential carbon impact per year across DNO area *relative* to traditional approaches for managing increasing fault levels			-542,928	2.90	**-542,926**

3.7 Extrapolation to the GB electricity distribution system

For the purposes of estimating the potential carbon saving of Respond if deployed across Great Britain (GB), an assumption is made that each of the 14 DNO licence areas are similar to ENW in terms of the number of sites with fault-levels that necessitate intervention, i.e., 12 per year.

Similarly, it is assumed that the split of I_S-Limiter/Adaptive Protection in each licence area would be similar to that applied above for extrapolating the results to ENW's DNO area, i.e., 80% Adaptive Protection and 20% I_S-Limiter.

Table 19 below shows the potential for Respond to save **7,432,431 kg CO_2e** per year, if deployed across the 14 DNO licence areas in Great Britain.

Table 19: Potential Respond carbon savings across Great Britain

Respond Technique	Comparative carbon impact per installation (kg CO2e)	No. of installations per year	Gross Carbon impact (kg CO_2e)	Transport of inserts (kg CO_2e)	Net Carbon impact across GB (kg CO_2e /year)
I_S-Limiter	-20,167	34	-677,611	49.23	-677,562
Adaptive Protection	-50,259	134	-6,754,869	0	-6,754,869
Total potential carbon impact per year across GB *relative* to traditional approaches for managing increasing fault levels			-7,432,480	49.23	**-7,432,431**

4 Carbon Impact of the Fault Current Limiting (FCL) service

4.1 Overview of FCL

FCL is a form of Adaptive Protection that can be deployed at the premises of customers who operate large alternating current (AC) rotating plant (such as generators and motors). The protection relays associated with these machines utilise an additional trip setting that can be engaged via remote command when fault level exceeds a pre-set level. This operates the equipment's circuit breaker more rapidly than normal, to curtail its fault current contribution to a system fault on the DNO's network.

As described in the *Fault Current Limiting Service Contract & Commercial Learning*[4] report published as part of the Respond project, it was not possible to trial the FCL technologies at customer sites as part of the Respond trial.

However, the design of FCL on-site is detailed in the *Fault Current Limiting Service Equipment Specifications and Installation Report*[5]. That report provided the basis for the carbon assessment described in this section.

4.2 Approach for calculating the carbon impact of the FCL service

The main equipment associated with the FCL service are the Adaptive Protection Relay and the Remote Terminal Unit (RTU) that enables communication with Electricity North West's telecontrol (SCADA) system. The RTU is powered by a Lead Acid Battery.

Therefore, the carbon impact of FCL can be calculated using the following formula:

$$CI_{FCL} = APr_{CI} + RTU_{CI}$$

Where:

$\boldsymbol{CI_{FCL}}$ is the carbon impact of FCLS

$\boldsymbol{APr_{CI}}$ is the carbon emissions from the Adaptive Protection Relay

$\boldsymbol{RTU_{CI}}$ is the carbon emissions from the RTU

4.3 Calculating the Carbon Assessment of the FCL

To derive the carbon impact of the FCL service, the embodied carbon of the Adaptive Protection Relay and the RTU, are assessed separately in the subsections below.

[4] https://www.enwl.co.uk/globalassets/innovation/respond/respond-key-documents/fcl-service-contract-and-commercial-learning.pdf

[5] https://www.enwl.co.uk/globalassets/innovation/respond/respond-key-documents/fcl-service-specification-and-installation-report.pdf

4.3.1 Carbon impact of Adaptive Protection relay

As described earlier in this report, ABB had previously developed an LCA for the SPACOM 100 Protection relays, and had calculated the embodied carbon of a protection relay to be circa 829 kg CO_2e.

That value (i.e., 829 kg CO_2e) is accordingly used in these analyses as an estimate of the carbon impact of the adaptive protection relay that is a key equipment installed at customer premises as part of the FCL service.

4.3.2 Carbon impact of the Remote Terminal Unit (RTU)

There were no examples from the literature or from previous ENW projects of an LCA being undertaken for an RTU. Accordingly, a bottom-up assessment was undertaken as part of this project, to estimate the embodied carbon in the RTU.

This was based on data provided by the manufacturers of the *Remsdaq F00590x Series* RTU.

As shown in Table 20 below, the bottom-up analyses indicated life cycle emissions of 108 kg CO_2e for the RTU (excluding the battery).

Table 20: Estimate of embodied carbon in the RTU

Material	Amount (kg)	Emission Factor	kg CO_2e
Aluminium	0.5	8.20E+00	4
Steel	39.6	2.30E+00	91
Copper	0.5	3.30E+00	2
Pressboard	0.8	1.39E-01	0
PVC	3.8	1.86E+00	7
Polyester	0.3	1.22E+01	4
Total	**45.5**		**108**

The RTU is powered by a Lead Acid battery (NPL24-12=9kg). Therefore, to estimate total emissions of the RTU (including the battery), the carbon emissions of the battery need to be assessed and incorporated.

There are numerous examples in the literature of LCA being undertaken of a Lead Acid Battery. See for example, Premrudee et al (2013) and Kassir et al (2016).

For the purpose of this analyses, the upper value from those analyses is used, which is 134 kgCO_2e for a Lead Acid battery over a 25 year life.

Therefore, the total life cycle embodied carbon in the RTU (including the battery) is estimated at 242 kgCO_2e as per Table 21 below.

Table 21: Carbon impact of the RTU (including battery)

	kg CO_2e
Embodied carbon in RTU	108
Embodied carbon in lead acid battery	134
Total	**242**

4.4 Total Carbon impact of the FCL Service

In summary therefore, the overall life cycle carbon impact of the FCL service is estimated at 1071 kg CO_2e as shown in Table 22 below.

Table 22: Overall carbon impact of the FCL service

FCL Equipment	kg CO_2e
Adaptive Protection	829
RTU (including battery)	242
Total	**1071**

It will be noted that a comparison of the carbon impact of the FCL service relative to traditional approaches for managing increasing fault-levels, was not undertaken. This is because the Respond trial did not ascertain how deploying FCL at customer premises might affect the useful life of network assets or the extent to which it might defer network reinforcement.

5 Conclusions and summary

The LCA of Respond's carbon impact shows that relative to traditional approaches, both the I_S-Limiter and Adaptive Protection provide opportunities for significantly reducing the carbon emissions associated with the management of fault levels on the network.

Indeed, each installation of an I_S-Limiter or Adaptive Protection has the potential to reduce carbon emissions by 20,167 kg CO_2e and 50,259 kg CO_2e respectively *vis-à-vis* traditional interventions for managing increasing fault levels on the electricity distribution network.

If rolled out across ENW's DNO area, Respond has the potential to save 542,926 kg CO_2e per year; and if rolled out across GB, 7,432,431 kg CO_2e per year can be saved.

The carbon impact of the FCL service is estimated at 1071 kgCO_2e per installation. The potential benefits of the FCL service on network assets' useful life was not ascertained as part of the Respond project. However, it will be noted that the FCL's gross carbon impacts are nominal, even without accounting for any carbon benefits that might arise from its effect on the useful life of network assets.

6 References

Jones, C (2018): *Deliverable 3.4.3 "Report on the Carbon Impact Implications of the Smart Street Method at ENWL and Great Britain Scale"*

Fthenakis V, Frischnecht R, Raugei M, Kim H. C., Alsema E, Held N, de Wild-Scholten M (2011): *Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity*, 2nd edition, IEA PVPS Task 12, 2011.

Jones, C (2017): Deliverable 3.4.2 "Second Interim Report on Carbon Accounting for the Smart Street project"

Marceau, Medgar L., Michael A. Nisbet, and Martha G. VanGeem (2007: *Life Cycle Inventory of Portland Cement Concrete*. Rep. no. 3011. Skokie: Portland Cement Association.

Premrudee K, Jantima U, Kittinan A, Naruetep L, Kittiwan K, Sudkla B (2013): *Life Cycle Assessment Of Lead Acid Battery - Case Study For Thailand.* Environ. Prot. Eng. 2013, 39, 101–114.

Kassir M, Mohammed H, Mohammed Dawood L (2016): *"Gate To Gate" Life Cycle Analysis Of Babel Lead Acid Battery*. Diyala Journal of Engineering Sciences, Vol. 09, No. 02, pp. 96-180, June 2016