Final Report for Ofcom

Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting

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1 Executive summary

Analysys Mason Limited (‘Analysys Mason’), together with Aegis Systems Limited (‘Aegis’), has been commissioned by Ofcom to carry out a study into the opportunity cost of the spectrum used by digital terrestrial TV (DTT) and digital audio broadcasting (DAB).

In this study, we have calculated the opportunity costs associated with the use of spectrum for a variety of applications. Our aim was to produce a quantitative assessment of opportunity costs which could be used by Ofcom as one of many inputs to a calculation of fees applied for the use of spectrum to provide DTT and DAB services.

This document presents the key findings of our study, including an explanation of the method used to calculate the opportunity costs both in ‘own use’ (i.e. the permitted use under the current allocation of the spectrum) and in ‘alternative use’ for the frequencies in question, specifically the ranges of 470–550MHz and 614–790MHz for DTT, and 211–230MHz plus 174–176MHz (Block 5A) for DAB.

Our study has focussed on a calculation of the relevant opportunity costs and not on the questions of whether or not AIP should be applied as a matter of principle, or whether rates of AIP should reflect the full opportunity cost. There may be other factors – such as wider benefits to society of certain spectrum uses or consideration of the impact upon investment in broadcasting content – that may need to be taken into account before such decisions are reached.

Our approach and the key results of our analysis are summarised in the remainder of this executive summary:

- We estimate that the total annualised opportunity cost[1] for all DTT spectrum lies between GBP61.4 million and GBP71.2 million. This results in an indicative average annualised opportunity cost of GBP10.2 million to GBP11.9 million per national DTT multiplex. However this estimate only considers the value of the spectrum in its current use, i.e. *before* consideration of alternative uses.[2]

- Unlike lower-frequency DTT spectrum bands, the DTT spectrum in the 700MHz band could be used by mobile operators. The value of the 700MHz spectrum when used for mobile telecoms (i.e. the cost savings to a generic mobile operator from having access to this spectrum) has been calculated at GBP1.58 million per MHz per annum. This is nearly 4 times the value of own use of this band for DTT.

1 All values are expressed in 2015 real terms.

2 The calculation of an average “per MUX” opportunity cost assumes that every MUX uses each grouping of channels equally.

- We consider that there is no excess demand for DAB spectrum or interleaved use of the DTT spectrum – which implies that this spectrum may have a zero opportunity cost. Furthermore our calculations suggested very low values[3] for the current users of this spectrum.

1.1 DTT and DAB frequencies considered

DTT (since the completion of digital switch-over) and DAB broadcasting in the UK are now delivered over several frequency bands:

- UK DTT uses frequencies in the ranges 470–550MHz and 614–790MHz. We consider these as three distinct sub-bands due to differences in alternative uses for the upper and lower part of the 614–790MHz block.

- UK DAB broadcasting currently only uses the frequencies 218–230MHz, though Ofcom has asked us to consider the larger DAB reserved range of 211–230MHz plus Block 5A (174–176MHz).

The DTT spectrum is also used on a secondary interleaved basis. This usage consists of high-power, long-range services (such as local TV) and low-power, local uses (such as PMSE).

Figure 1.1 below lists the relevant frequency blocks and other potential alternative uses for each relevant block. As noted above, we have split the 614–790MHz block into two separate entries in our analysis because the alternative uses in different parts of this block may be very different.

The 700MHz band (694–790MHz), for example, has a strong likelihood of international harmonisation for mobile services. This follows the provisional decision at WRC-12 to allow for a co-primary mobile allocation in the 700MHz band within ITU Region 1. This co-primary allocation to mobile and broadcasting is scheduled to be approved at WRC-15, subject to relevant technical work. We note also that Ofcom has published a UHF Strategy Statement[4] which sets out the current intention to re-allocate the 700MHz band for mobile usage.

Figure 1.1: Summary of relevant spectrum bands [Source: Analysys Mason, 2012]

Spectrum blocks	Other possible UK use
174.160–175.696MHz (Block 5A – currently PMSE)	May be moved to DAB on a local scale
210.880–229.840MHz (DAB blocks 10B to 12D)	PMR, PMSE, DTT or fixed links
470–550MHz (DTT channels 21 to 30)	PMR, local TV or PMSE
614–694MHz (DTT channels 39 to 45)	PMR, local TV or PMSE
694–790MHz (DTT channels 49 to 60).	Mobile (data and voice), PMR, local TV or PMSE

3 Despite there being no excess demand for spectrum, there may be a non-zero cost to current users of the spectrum if they are no longer able to use it. This implies that the spectrum has a value to these users.

4 'Securing long term benefits from scarce low frequency spectrum', Ofcom, November 2012.

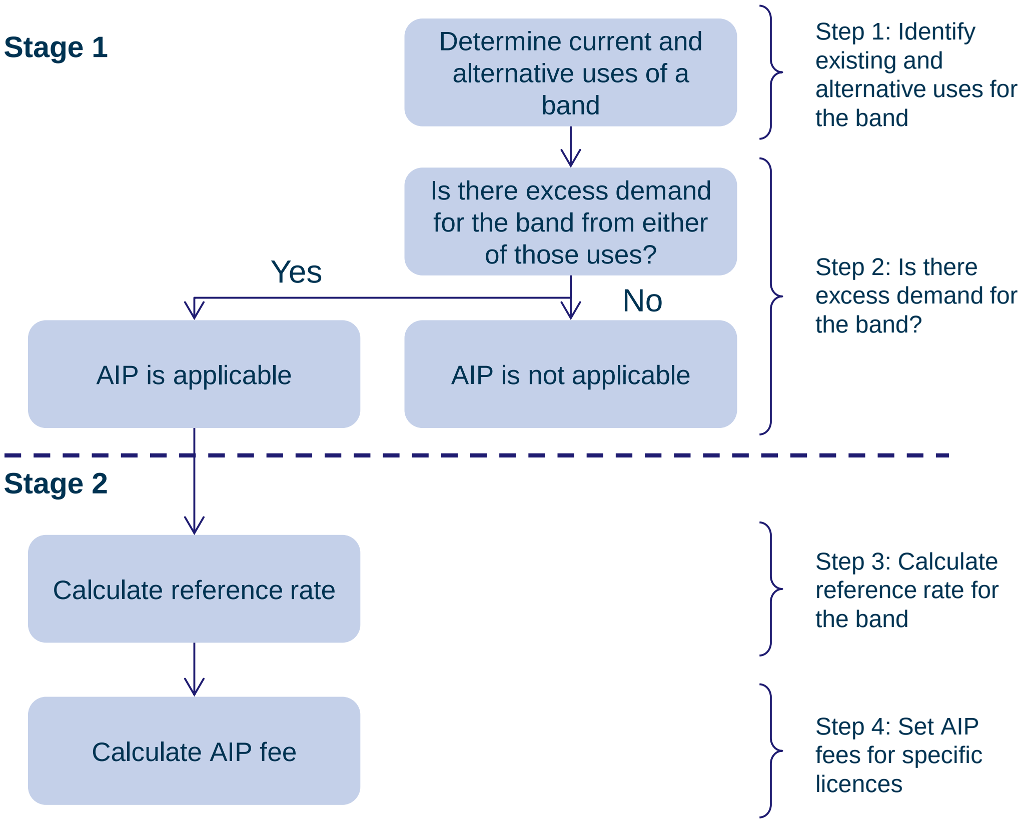
Our modelling of the opportunity costs assumes that spectrum is lost or gained in indivisible units that are equivalent to the standard spectrum channel widths used at that frequency. DTT spectrum is therefore modelled as 8MHz channel increments, and DAB spectrum is modelled as 1.5MHz channel increments.

1.2 Methodology for calculating opportunity costs

Our analysis and the modelling of opportunity costs discussed in this document are designed to be consistent with Ofcom's updated principles and methodologies for setting AIP fees[5], which were published in 2010.

We have taken this approach to give Ofcom the option to use our opportunity cost calculations as an input to a subsequent decision it may make on the level of AIP to apply to DTT and DAB spectrum. The overall methodology is summarised in Figure 1.2, although as described below, only certain steps are relevant to the opportunity cost calculations set out in this document:

Figure 1.2: Stages and steps in the calculation of spectrum AIP fees [Source: Ofcom, 2010]



This document is relevant to Steps 1, 2 and 3. If Ofcom decided to impose AIP, our calculations in Step 3 may be used as one of the inputs into Ofcom's calculation of AIP fees in Step 4.

5 'Appendix A: Our current practice in setting AIP fees', Ofcom, March 2010.

The first stage is therefore to establish whether the spectrum in each band is a scarce resource. If the spectrum is not scarce then arguably it has a zero opportunity cost and a reference rate does not need to be calculated. We based our decisions on scarcity around three main considerations:

- Is the spectrum currently (or does it seem likely to become) heavily congested under its current own use?
- If the spectrum is not congested, is this due to an artificial limiting factor (for example the restriction of licences)?
- Is there a realistic alternative use of the spectrum, and if so, is there excess demand from any of these alternative uses?

If there is excess demand for a particular band from both existing and alternative uses, two values need to be calculated:

- *the value in own use*: this corresponds to the value of the spectrum in its current use
- *the value in alternative uses*: this corresponds to the value of the spectrum in other potential uses that appear feasible within a relevant timeframe.

There are two different approaches to calculate the value in own use and the value in alternative uses: the least-cost alternative (LCA) approach and the discounted profits (DP) approach. Both approaches are summarised in Figure 1.3 below.

Figure 1.3: Summary of the LCA and DP approaches [Source: Analysys Mason, 2012]

	Own use	**Alternative uses**
LCA	For a current average user of the band, the difference between the cost of delivering services using current level of spectrum and the long term least-cost alternative production method following the loss of a small block of spectrum in the band. The user maintains the same level of output.	Cost saving that an average provider of an alternative service could achieve if given access to a small block of spectrum in the band
DP	Change in discounted cashflow that an average current user of that band would incur from losing a licence giving access to a block of spectrum from that band. This method may be preferred when it is no longer realistic to assume that output is kept constant.	*Change in discounted cashflow that an average alternative user would generate from holding a licence giving access to a block of spectrum from that band.* *(We do not consider this DP method in our analysis of alternative uses)*

For own use, we estimate opportunity cost using both methods. However, for alternative uses, Ofcom has asked us to consider only the LCA approach.[6]

6 This is because Ofcom is already undertaking analysis of the value of mobile broadband in the 700MHz band which would be equivalent to a DP approach.

For both the LCA and DP approaches we have built models to calculate discounted free cashflow to perpetuity. We have constructed one model for each type of spectrum usage (e.g. DTT, DAB, mobile) and for each approach to opportunity cost modelling (i.e. LCA and DP).

For both DTT and DAB, there are operators of public service broadcaster (PSB) and commercial (COM) multiplexes (MUX). These operators are the spectrum licensees and our cost models are therefore based at a MUX operator level[7]:

- On the revenue side, the own use models account for any changes in income for commercial MUX operators (e.g. payments for MUX slots); on the PSB side, revenues are likely to be less relevant unless a change in output (i.e. the number of TV stations broadcast and the area covered) were possible.
- On the cost side, we have modelled capital and operational costs, benchmarked against available information on UK broadcast network costs.

LCA – own use

For the LCA approach in own use, we have considered several possible options for MUX operators to maintain production levels following a loss of spectrum. These are described in Section 1.4 for DTT and Section 1.5 for DAB. We note that these different responses are hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum. In particular we assume in calculating the opportunity costs of DAB and DTT spectrum that any statutory or licensing barriers to MUX operators responding to a (hypothetical) loss of spectrum have been removed.

For both DAB and DTT we compare the cashflow generated by a MUX operator with its existing spectrum holding and with a lower amount of spectrum. The magnitude of the loss of cashflow in the reduced spectrum scenario will differ according to how the operator chooses to respond to the loss of spectrum. However, all possible responses will lead to some degree of cashflow reduction relative to the operator retaining all of its existing spectrum holding.

The loss of cashflow represents the value of the lost spectrum to the operator[8]. We express this reduction in cashflow as a net present value (NPV) in 2015 real terms.

This NPV is then normalised to ensure a common basis for comparison, by calculating the value per MHz per annum[9]. This allows us to compare the costs of different responses to a loss of spectrum by a MUX operator. The lowest of these normalised costs forms the LCA in own use.

[7] For vertically integrated firms operating MUXs, such as Arqiva and the BBC, we focus only on the MUX operator business unit and ignore any incentives and costs brought about through vertical integration.

[8] Specifically it represents the difference in the cost of production using the operator's existing spectrum holding and the cost of production using the reduced spectrum holding under consideration.

[9] To normalise the NPV we calculate an annual cost which, if it were to remain flat in real terms would recover the full NPV including terminal value when summed into perpetuity.

LCA – alternative use

For the LCA approach in alternative use we have followed a similar approach but instead modelled the increase in cashflow (i.e. cost saving in the context of the LCA approach) that would result from an alternative use being given access to the spectrum.

DP – own use

The DP value (considered only in own use) is the difference between the cashflow of delivering a service using the current spectrum and the profit-maximising production method following the loss of an amount of spectrum, where the same level of output does not need to be maintained.

Under this approach there is a trade-off between the costs incurred by a MUX operator to mitigate the loss of spectrum, and the revenues which might be foregone by not fully mitigating the impact of a loss of spectrum. In other words, if the cost of maintaining output levels after the loss of spectrum would outweigh the revenue benefits, then the MUX operators may choose not to restore output levels.

The most prominent examples of this trade-off relate to cases where the mitigation for lost spectrum requires an upgrade to CPE (e.g. for a DVB-T2 upgrade of the DTT platform): MUX operators may opt not to provide users with replacement CPE (or to not offer a full subsidy). If a MUX operator chose not to subsidise new STBs then a number of end users of DTT may switch to another television platform. This might imply lower viewing of DTT programmes, with implications for the broadcasters' advertising revenues. Reduced advertising revenue for TV station providers may reduce their willingness to pay for commercial MUX slots. Any reduced payments from broadcasters as a consequence of a reduction in DTT viewers will be weighed up by MUX operators against the costs of upgrading CPE.

In general, our cost calculations for own use have been designed to provide cost estimates for different approaches to mitigating a loss of spectrum. With some of these options there may be significant practical difficulties, which are discussed further in Section 8.2. It may be that Ofcom considers in some cases that these practical difficulties are insurmountable or that the option is otherwise not viable in practice. If Ofcom were to decide that an option was impractical, one response could be to take the next lowest-cost alternative (or next lowest DP-based cost) as the relevant opportunity cost.

1.3 Assessing scarcity/excess demand

We have investigated the level of expected demand in 2015 for both DTT and DAB spectrum. From our analysis we conclude that spectrum scarcity is likely to exist for the primary use of the DTT spectrum bands. However, we do not believe that spectrum scarcity is likely to exist for either the DAB spectrum or in secondary interleaved use of the DTT spectrum.[10]

[10] Whilst local TV services may impose some extra constraint on PMSE services, we do not consider the spectrum available for PMSE to be scarce at this time.

While this document is not intended to determine whether charging AIP to broadcasters for scarce spectrum is appropriate, our findings as regards scarcity would imply that, if AIP were to be charged, it should only be considered for application to national DTT services, and not to local TV services, to DAB or to PMSE in the bands considered.

1.4 Determining opportunity costs in own use and alternative use for DTT spectrum

1.4.1 DTT spectrum in own use

We have identified four potential responses by DTT MUX operators to a loss of spectrum, and have modelled each of these to estimate the LCA. This is discussed in more detail in Section 4.3. As noted above, these different responses are intended as hypothetical scenarios designed to allow the modelling of the opportunity costs of the spectrum.[11]

In the future these options may change: some may no longer be applicable. On the other hand, new options may emerge, for example due to technological or market developments.

For example, we note from the recent UHF Strategy Statement that Ofcom intends to allow DTT broadcasting to make use of the 600MHz band in place of the 700MHz band (which is to be re-allocated to mobile services at some future point). If this switch were to occur, a migration to the 600MHz band would no longer be a viable response to a loss of spectrum (as they would already be located in this spectrum); the lowest cost of the other potential responses (or any new response options which have arisen by that time) could then be considered.

The 4 different responses considered are:

- **Migrate users from DTT to another platform**, namely Freesat.
- **Implement technology upgrades to increase capacity** within the remaining spectrum. We consider the most sensible options to be upgrading of transmission technologies to DVB-T2 (with MPEG-4 compression), as this has already been carried out for the current high-definition PSB MUX, and is seen as a logical progression.
- **Move to a different infrastructure** for some or all MUXs (e.g. use of a single-frequency network in Channel 36. Due to increased guard band requirements, any such move would also entail a DVB-T2 upgrade).
- **Migration to the 600MHz band** (UHF Channels 31-37).

[11] For instance, we recognise that MUX operators do not have the right to freely move to using the 600MHz band due to constraints of their licences under the Broadcasting Act. However, in line with other assumptions we do not consider this an impediment when calculating their opportunity cost of the spectrum based on a hypothetical scenario of migrating to use the 600MHz band.

The costs calculated under both LCA and DP cases are summarised in Figure 1.4 below[12].

Figure 1.4: Costs for DTT across each different response to a loss of DTT spectrum under LCA and DP cases (in CPE replacement Scenario 1[13]) [Source: Analysys Mason, 2012]

Mitigation response	Ch. 21 to 30 (GBP thousand/ MHz/annum)	Ch. 39 to 48 (GBP thousand/ MHz/annum)	Ch. 49 to 60 (GBP thousand/ MHz/annum)	Indicative average annual cost per MUX (GBP million)
LCA: Switch DTT platform to Freesat	1238	1238	1238	52.8
DP: Switch DTT platform to Freesat	718	718	718	30.6
LCA: Upgrade MUXs to DVB-T2	532	394	**413**	19.0
DP: Upgrade MUXs to DVB-T2	454	342	357	16.3
LCA: Upgrade MUXs to SFN and DVB-T2	538	522	482	21.9
DP: Upgrade MUXs to SFN and DVB-T2	451	438	405	18.3
LCA: Move 7 channels to 600MHz band	**74**	**321**	424	12.1
DP: Move 7 channels to 600MHz band	**74**	**270**	**353**	10.2
Lowest LCA combination across all sub-bands	74	321	413	**11.9**
Lowest DP combination across all sub-bands	74	270	353	**10.2**

Note: Values in red represent the lowest-cost response for each sub-band

Under both the LCA and DP approaches, the lowest-cost mitigation strategy for loss of spectrum in either Channels 21–30 or Channels 39–48 is the move of 7 channels to the 600MHz band.

The lowest-cost mitigation strategy for Channels 49–60 in the LCA case is the upgrade of the DTT broadcasting technology to DVB-T2. However, under the DP approach the move of 7 channels to the 600MHz band remains the lowest-cost response.

Switching to the Freesat platform is the most costly mitigation response because it involves not only the provision of new CPE but also a loss of future profits on the DTT platform. Options involving a DVB-T2 upgrade also require the replacement of CPE. However, moving channels to

12 All values are expressed in 2015 real terms.

13 We have modelled 4 CPE replacement scenarios for DTT and in this Executive Summary show results only for Scenario 1. This scenario requires MUX operators (under the LCA approach) to provide a replacement STB for all primary household TV sets which are primarily used for DTT, but not any further DTT household sets, should the response entail a change of user equipment.

the 600MHz band requires only some receiver aerials to be replaced. In general therefore this has the lowest cost of the mitigation responses considered.

Channels 49–60 are the range often referred to as the 700MHz band. This band has the highest cost in own use of any of the DTT spectrum. However, as shown in Section 1.4.2, this spectrum band also has substantial value in alternative (mobile) use which does not exist for the other DTT spectrum bands.

Based on the results above, the total annualised opportunity cost in own use for all DTT spectrum is around GBP71.2 million under LCA and GBP61.4 million under DP[14]. This gives us an indicative average opportunity cost of between GBP10.2 million and GBP11.9 million per national DTT multiplex *before* consideration of value in alternative uses. The calculation of an average 'per-MUX' opportunity cost assumes that every MUX uses each grouping of channels equally. We also note that the actual opportunity cost for each individual MUX may differ from the average, which is simply obtained by dividing the total value by 6 (the number of MUXs). For example, PSB and COM MUXs may have different opportunity costs for the spectrum due to different coverage obligations and different numbers of sites, as we discuss in more detail in Section 4.2.2.

Interleaved use of DTT spectrum – value in own use

The costs of different responses by local TV providers to a loss of spectrum calculated under both LCA and DP approaches are summarised in Figure 1.5 below[15].

Mitigation response	LCA case (GBP thousand/MHz/annum)	DP case (GBP thousand/MHz/annum)
Move to alternate frequency channel	**51.2**	**2.2**
Switch local TV to a national MUX	69.9	27.5
Close local TV	N/A	17.8

Figure 1.5: Costs for local TV spectrum mitigation under LCA and DP cases in CPE replacement Scenario 1 [Source: Analysys Mason, 2012]

Note: Values in red represent the lowest-cost response for each approach

The LCA and DP values for moving to another frequency are markedly different. This is because the DP approach does not require replacement receiving aerials to be provided to households that do not offer high value to the platform.

14 The 'Channels 21 to 30' consists of ten 8MHz channels totalling 80MHz. The other two groupings total 80MHz and 96MHz. These bandwidths are multiplied by the minimum LCA and DP opportunity costs, highlighted in red in the table, to result in total opportunity costs in own use of GBP71.2 million per annum under LCA and GBP61.4 million per annum under DP.

15 All values are expressed in 2015 real terms.

The costs of different responses by users of the smaller geographical area interleaved DTT spectrum, such as PMSE services, are summarised in Figure 1.6 below[16].

Figure 1.6: Mitigation costs for PMSE spectrum spread across all DTT spectrum, under LCA and DP [Source: Analysys Mason, 2012]

Mitigation response	Ch. 21 to 30 (GBP thousand/MHz/annum)	Ch. 39 to 48 (GBP thousand/MHz/annum)	Ch. 49 to 60 (GBP thousand/MHz/annum)
LCA+DP: Moving entire sub-band	9.1	9.1	9.1
LCA+DP: Moving one channel	**1.8**	**1.8**	**1.8**

Note: Values in red represent the lowest-cost response for each sub-band

Under both LCA and DP, the lowest-cost mitigation strategy for a spectrum loss (of one channel) in either Channels 21–30, 39–48 or 49–60 is to move to another frequency. This is very low at only around GBP1800 per MHz per annum.[17]

1.4.2 DTT spectrum in alternative use

The key alternative use for the DTT spectrum in the 700MHz band is mobile services, and specifically LTE-based services (largely consisting of mobile broadband). The case for use of the 700MHz spectrum band for mobile broadband is prevalent.[18] Ofcom's recent statement on the future strategy for UHF Bands IV and V has indicated that the 600MHz band may play a role in mitigating the 700MHz loss.

Notwithstanding any practical difficulties of re-allocation of the 700MHz band, in this study we provide calculations of the opportunity cost of the 700MHz spectrum for mobile use.

Due to the economies of scale gained through the use of internationally harmonised bands for mobile services, it is highly likely that the 700MHz band will offer significant value to mobile users.

Conversely, international harmonisation of bands and the resulting economies of scale in handset manufacturing mean that bands which are not internationally harmonised are unlikely to offer such significant value to mobile operators. Moreover, below 700MHz it is possible that spectrum may be inherently less attractive for public mobile services, potentially requiring the use of larger antennas in devices, which may, to some extent, be less cost-effective. Therefore we consider that

16 All values are expressed in 2015 real terms.

17 The cost of moving one channel is lower than the cost of moving an entire sub-band and in both cases the per-MHz normalisation is carried across the entire sub-band, resulting in a lower per MHz cost for moving a single channel.

18 The provisional decision at WRC-12 allows for a co-primary mobile allocation in the 700MHz band within ITU Region 1 to be approved for mobile broadband at WRC-15, subject to relevant technical work.

no UHF spectrum below the 700MHz band is likely to be used for a purpose other than DTT in the foreseeable future and have therefore only modelled mobile services in the 700MHz band.

We have identified mobile services as the only alternative use of DTT spectrum which results in higher potential value than in own use, and even then only within the 700MHz band.

Approach to modelling the opportunity cost of the 700MHz band for mobile use

In general, there may be many sources of value of additional spectrum to a mobile operator. In the context of an LCA calculation we believe that it would only be appropriate to include the network cost savings related to the *technical* value of the additional spectrum. As a result, our model of the opportunity cost of the 700MHz band for mobile communications as an alternative use considers only the network cost savings achievable by a mobile operator through having access to additional spectrum in the 700MHz band.

There are likely to be other sources of commercial value to mobile operators, such as the ability to serve more customers or deliver greater consistency of coverage. However, our approach of focusing on the cost savings effectively assumes that output is constant, which is consistent with the LCA methodology.

We base our model around the spectrum requirements of a generic operator. Our calculations of network cost savings are based on an assessment of the number of sites which the modelled generic operator could avoid building if more spectrum (in the 700MHz band) were to be made available to it. We model over a 20 year period from the start of 2015 but include a terminal value in our assessment of the present value of costs faced by the generic operator.

Both the total technical value and the annualised per-MHz technical value of the spectrum to the generic mobile operator are shown in Figure 1.7 below[19]. As more spectrum is provided to the generic mobile operator, the value it derives decreases on a per-MHz basis, providing a range of estimates:

Figure 1.7: Value of 700MHz spectrum [Source: Analysys Mason, 2012]

	Generic mobile operator acquires 2×5MHz block of spectrum	Generic mobile operator acquires 2×10MHz block of spectrum	Generic mobile operator acquires 2×15MHz block of spectrum
Total technical value (GBP million)	378	539	606
Annualised technical value (GBP million/MHz/annum)	2.21	**1.58**	1.18

Note: The value in red represents our central opportunity cost estimate for mobile use of the 700MHz band

19 All values are expressed in 2015 real terms.

We have also run various sensitivity analyses in order to test the impact of changes in various model inputs on the spectrum valuation for mobile use. These are described in more detail in Section 5.1.3.

1.5 Determining opportunity costs in own use and alternative use for DAB spectrum

We have identified 4 potential responses by DAB MUX operators to a loss of spectrum, and have modelled each of these to find the LCA as discussed in Section6.4. As with DTT spectrum, these different responses are not necessarily real options which MUX operators might consider, but rather hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum.

The 4 different responses modelled (including 2 separate responses involving switches to alternative platforms) are:

- **Implement a technology upgrade to increase capacity** within the remaining spectrum. We consider the most likely option to be upgrading the DAB transmission technology to DAB+.
- **Move to a different spectrum channel**, which due to the typical tuning range of DAB receivers could ideally be any spare spectrum within VHF Band III.
- **Migrate users from DAB to an FM platform.**
- **Migrate users from DAB to a DRM+ platform**. We consider FM or DRM+ to be the closest relevant alternatives to DAB due to their similar characteristics, though note that a move to DRM+ could probably only occur if the FM spectrum had been vacated as part of digital radio switchover.

One of the largest uncertainties in modelling the opportunity costs for DAB in 2015 is the state of the digital radio switchover at that time. To address this uncertainty we have modelled 4 potential digital switchover scenarios, as discussed in the recent report on the '*Cost-benefit analysis of radio switchover*' (CBA report) by the Department for Culture Media and Sport (DCMS)[20]:

- Counterfactual: No digital switchover
- DSO Scenario 1: UK-wide switchover in 2015
- DSO Scenario 2: UK-wide switchover in 2018 following market trends (i.e. at a time when DAB is assumed to have reached similar coverage and listenership to FM)
- DSO Scenario 3: Phased nation-by-nation switchover (England switches in 2017, Wales in 2018 and Scotland and Northern Ireland in 2019).

20 See http://www.culture.gov.uk/images/publications/CBA_Radio_Switchover_Methodology_Report_July12.pdf

We have calculated the costs of the different responses to a loss of DAB spectrum using both the LCA and DP approaches. The results are summarised in Figure 1.8 below[21].

Figure 1.8: Costs across each different response to a loss of DAB spectrum under both LCA and DP cases (in CPE Scenario 2[22]) [Source: Analysys Mason, 2012]

Mitigation response	Counterfactual (GBP thousand/ MHz/annum)	DSO Scenario 1 (GBP thousand/ MHz/annum)	DSO Scenario 2 (GBP thousand/ MHz/annum)	DSO Scenario 3 (GBP thousand/ MHz/annum)
LCA: Upgrade of MUXs to DAB+	9306	18 227	7876	9208
DP: Upgrade of MUXs to DAB+	1794	3603	2069	2407
LCA: Moving 1 channel to a new frequency	**98**	**101**	**95**	**96**
DP: Moving 1 channel to a new frequency	**98**	**101**	**95**	**96**
LCA: Switching 1 channel's stations onto FM	427	1352	376	380
DP: Switching 1 channel's stations onto FM	370	1233	376	380
LCA: Switching all stations onto DRM+	N/A	27 487	N/A	14 881
DP: Switching all stations onto DRM+	N/A	9528	N/A	6900

Note: Values in red represent the lowest-cost response for each approach

The lowest cost (shown in red in Figure 1.8), under all of the radio DSO scenarios, arises from the move of one or more channels' content to a different frequency within VHF Band III. We note that the move to a different spectrum channel considers a move to Channel 11A and other empty channels currently reserved for DAB in the first instance. However, this cost would remain constant for migration to any channel within VHF Band III. In practice though, Ofcom may wish to consider the difficulties of clearing spectrum outside of the current DAB reserved spectrum, including any difficulties in relation to international coordination.

The costs for switching to DRM+ and upgrading to DAB+ are both significantly higher than for moving a channel's content to a new frequency because they require the provision of new radio receivers for the majority of listeners (all listeners in the case of DRM+), which is very costly. For switching to FM there is a cost for new transmitters, whilst for changing the channel being used only a (lower-cost) new combiner is required.

21 All values are expressed in 2015 real terms.

22 We have modelled 3 CPE replacement scenarios for DAB and in this Executive Summary show results only for CPE replacement Scenario 2. This scenario requires MUX operators (under the LCA approach) to replace all DAB car radios and all primary DAB household radios, but not any further DAB household radios, should the response entail a change of user equipment.

We did not find any alternative uses for the DAB spectrum which were of higher value than DAB.

As DAB MUXs make exclusive use of the spectrum using single frequency networks, we do not investigate interleaved usage of the spectrum within the DAB channels.

1.6 Conclusions

For the three DTT sub-bands and the two DAB sub-bands, we have assessed the costs of spectrum loss mitigation under both the LCA and DP approaches. The lowest cost results are summarised in Figure 1.9 below[23]. In all cases the costs are normalised on a per-MHz, per-annum basis. The values shown represent the first year's opportunity costs in a series of per-annum opportunity costs calculated so as to be flat in real terms into perpetuity. Where spectrum is not considered scarce the values calculated for current users would represent the opportunity costs were the spectrum to be considered scarce.

Figure 1.9: Results of calculation of the opportunity costs of the DTT and DAB spectrum [Source: Analysys Mason, 2012]

GBP thousand/MHz/annum	Excess demand	Own use LCA	Own use DP	Alternative use LCA
DAB Channels 11B to 12D	None	95–101[24]	95–101	0
DAB other Band III channels	None	0	0	0
DTT Channels 21 to 30	In own use	74	74	0
DTT Channels 39 to 48	In own use	321	270	0
DTT Channels 49 to 60	In own and alternative use	413	353	1580

For national DTT, opportunity costs vary across the different DTT sub-bands. For Channels 21-30 the opportunity cost is relatively low at only GBP74 000 per MHz per annum. This is because it is possible (hypothetically) to migrate channels from this sub-band to the 600MHz band without having to replace any receiving aerials. In the other DTT sub-bands the opportunity costs are relatively higher as a migration to the 600MHz band is not quite as straightforward, even if it remains the lowest opportunity cost option in most cases.

In the 700MHz band (Channels 49 to 60) however, there is also a substantial opportunity cost in alternative use (mobile) which is significantly higher than the opportunity cost in own use.

For DAB, the opportunity cost estimates range between GBP95 000 and GBP101 000 per MHz per annum depending on the DSO scenario considered. These opportunity costs are relatively low, in addition to the spectrum not being scarce. However, we do note that, should migration to other channels within VHF Band III or to the FM platform be considered impossible, the opportunity cost of the spectrum in own use would be considerably higher.

[23] All values are expressed in 2015 real terms.

[24] Dependent upon radio DSO scenario.

2 Introduction

Analysys Mason Limited (‘Analysys Mason’), together with Aegis Systems Limited (‘Aegis’), has been commissioned by Ofcom to carry out a study into the opportunity cost of the spectrum used by digital terrestrial TV (DTT) and digital audio broadcasting (DAB).

In this study, we have calculated the opportunity costs associated with the use of spectrum for a variety of applications. Our aim was to produce a quantitative assessment of opportunity costs which could be used by Ofcom as one of many inputs to a calculation of fees applied for the use of spectrum to provide DTT and DAB services.

In this document we present the key findings of our study, including an explanation of the method used to calculate the opportunity costs both in ‘own use’ (i.e. the permitted use under the current allocation of the spectrum) and in alternative use for the frequencies in the ranges of 470–550MHz and 614–790MHz for DTT, and 211–230MHz plus 174–176MHz (Block 5A) for DAB.

Our study has focussed on a calculation of the relevant opportunity costs and not on the questions of whether or not AIP should be applied as a matter of principle, or the rates at which it should be applied. For example there may be other factors such as wider benefits to society of certain spectrum uses or consideration of the impact upon investment in content which may need to be taken into account before such decisions are reached.

A previous study by Indepen and Aegis[25] into the application of AIP to terrestrial broadcasting provided a discussion of the level of excess demand for DTT and DAB spectrum and the appropriate methods for the calculation of opportunity costs for this spectrum. We discuss these points further in Section 3.

We note that since the Indepen/Aegis study was completed, many changes have occurred in the broadcasting landscape, including the near completion of TV digital switch-over (DSO), the introduction of high-definition (HD) services on Freeview (facilitated by DVB-T2),and indications of a future radio DSO.

In addition, several of Indepen/Aegis’s anticipated market developments have not materialised. Demand for DAB MUX slots has been significantly lower than expected and mobile TV services using DVB-H (predicted to be deployed using UHF spectrum) have yet to emerge. Instead we have seen a rise in the popularity of video on demand catch-up TV services (such as BBC iPlayer) and Internet radio, and an explosion in usage of mobile data traffic, which has led to key changes in mobile harmonisation (such as provisional agreement at WRC-12 to allocate the 700MHz band to mobile usage on a co-primary basis at WRC-15[26]).

25 ‘Study into the potential application of Administered Incentive Pricing to spectrum used for Terrestrial TV & Radio Broadcasting’, Indepen and Aegis, on behalf of Ofcom, Oct 2005.

26 694–790MHz, although the precise frequencies will be confirmed at WRC-15

Noting the various changes that have taken place both in terms of broadcast service delivery and in terms of alternative uses of spectrum used for broadcasting, we have re-assessed the market assumptions contained in the earlier Indepen/Aegis report, in order to establish whether spectrum is now scarce for DTT and for DAB, as well as to establish which alternative uses currently have the highest opportunity costs.

The remainder of this document is laid out as follows:

- Section3 discusses the key considerations in calculating the opportunity costs
- Section 4 describes the modelling of the opportunity cost of the DTT spectrum in own use
- Section 5 describes the modelling of the opportunity cost of the DTT spectrum in alternative use
- Section 6 describes the modelling of the opportunity cost of the DAB spectrum in own use
- Section 7 describes the modelling of the opportunity cost of the DAB spectrum in alternative use
- Section 8 discusses the conclusions arising from the opportunity cost results and the implications for AIP prices.

At the beginning of each section we provide a guide to the location of the key points discussed within that section.

The document also includes a number of annexes containing supplementary material:

- Annex A provides a glossary of terms used within this document
- Annex B provides a detailed discussion of the DTT aerial replacement calculations
- Annex C provides the detail behind the mobile spectrum price benchmarks, used as a cross-check to our calculations.

3 Considerations relating to opportunity cost calculations

In recent years various developments have taken place in the broadcasting market:

- DSO of TV signals has now been completed; 98.5% of households are covered by digital public service broadcasting (PSB) transmissions, and 90% by commercial transmissions. In practice, this now means that for 10 million homes, DTT is the only means currently used to receive digital TV services.
- Alternative platforms for receiving digital TV and radio content have emerged, in particular IPTV services (such as those offered by BT Vision), and Internet radio. In addition, many national DAB stations are also available over the Freeview DTT platform.
- One DVB-T2 MUX has been deployed in the UK, although the cost of DVB-T2 receivers still remains high in comparison to standard DTT sets.
- The Government has tentatively indicated that large-scale AM/FM radio broadcasts may be shut down in future, with most radio services, including larger local radio stations, being migrated to DAB (although there is a presumption that some smaller local radio stations may stay on AM/FM).
- The 800MHz sub-band has been cleared of DTT use, harmonised for use by mobile broadband services, and was auctioned by Ofcom in 2013. There is also an emerging demand for more UHF spectrum to be identified for mobile use as demonstrated by the provisional WRC-12 decision on the 700MHz band.

These developments all form important considerations through the remainder of this section, which begins with a discussion of the spectrum bands relevant to our study (in Section 3.1). Next we provide a summary of the context of our opportunity cost calculations in Section 3.2. We then provide an overview of the methodology for determining scarcity in Section 3.3 and for calculating opportunity costs in Section 3.4. In Section 3.5 we discuss the frequency with which the opportunity costs and determinations of scarcity might need to be updated.

The remainder of this section is therefore set out as shown in Figure 3.1 below.

Figure 3.1: Map of Section 3 [Source: Analysys Mason, 2012

3.1 The DTT and DAB spectrum bands

Following the completion of TV DSO, the spectrum used for DTT and DAB broadcasting within the UK is drawn from several frequency bands:

- DTT occupies the frequencies 470–550MHz and 614–790MHz. These we consider as three separate blocks, with the 614–790MHz block considered as two separate segments due to differences in alternative uses for the upper and lower part of this range.
- DAB broadcasting currently only uses the frequencies 218–230MHz, though Ofcom has shown interest in the larger DAB reserved range of 211–230MHz plus Block 5A (174–176MHz).

Figure 3.2 below lists the relevant frequency blocks and other potential alternative uses for each relevant block. We have split the 614–790MHz block into two separate entries in our analysis because the alternative uses in different parts of this block may be very different. In particular the 700MHz band (694–790MHz) has a strong likelihood of international harmonisation for mobile services. This follows the provisional decision at WRC-12 to allow for a co-primary mobile allocation in the 700MHz band within ITU Region 1. This co-primary allocation to mobile and broadcasting is scheduled to be approved at WRC-15, subject to relevant technical work.

The recently released UHF Strategy Statement[27] sets out Ofcom's current intention to re-allocate the 700MHz band for mobile usage. This Statement has indicated that if the DTT platform in the UK is re-planned without the 700MHz band, then the 600MHz band (i.e. UHF Channels 31 to 37, 550-614MHz) is likely to play a significant role in providing substitute spectrum for DTT.

27 'Securing long term benefits from scarce low frequency spectrum', Ofcom, November 2012.

Nevertheless, our DTT spectrum opportunity cost calculations are based on the spectrum currently used to provide DTT services.

Figure 3.2: Summary of relevant spectrum bands [Source: Analysys Mason, 2012]

Spectrum blocks	***Other possible UK use***	***Other (non-broadcasting) uses seen internationally***
174.160–175.696MHz (Block 5A – currently PMSE)	May be moved to DAB on a local scale	PMSE
210.880–229.840MHz (DAB blocks 10B to 12D)	PMR, PMSE, DTT or fixed links	Maritime mobile, radiolocation (Region 2)
470–550MHz (DTT Channels 21 to 30)	PMR, local TV or PMSE	Fixed links (Region 2)
614–694MHz (DTT Channels 39 to 45)	PMR, local TV or PMSE	Public safety use (USA)
694–790MHz (DTT Channels 49 to 60).	Mobile (data and voice), PMR, local TV or PMSE	Mobile services, emergency services mobile data

We explore these alternative uses in more detail in Section 5 for the DTT spectrum and Section 7 for the DAB spectrum.

3.2 The context of the calculation of opportunity costs

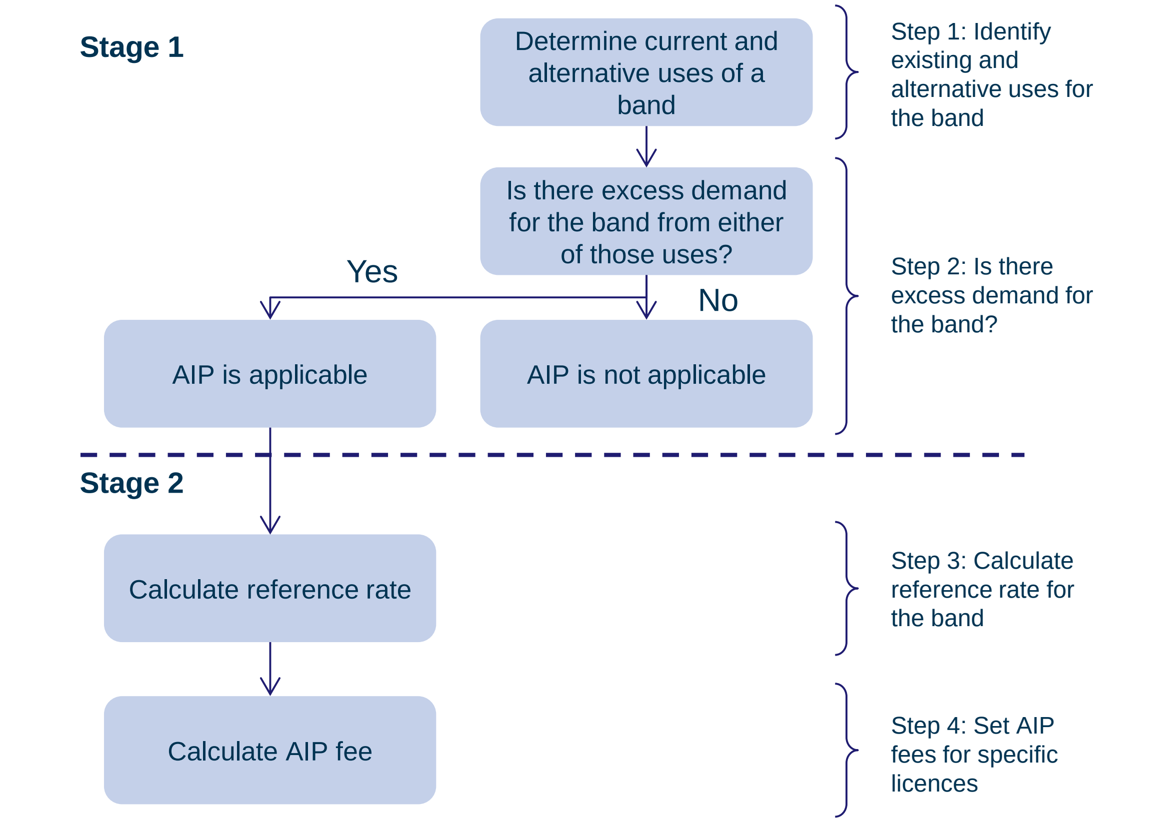
Our analysis and the modelling of opportunity costs discussed in this document are designed to be consistent with Ofcom's updated principles and methodologies for setting AIP fees[28], which were published in 2010.

We have taken this approach to give Ofcom the option to use our opportunity cost calculations as one of many inputs to a subsequent decision it may make on the level of AIP to apply to DTT and DAB spectrum.

28 'Appendix A: Our current practice in setting AIP fees', Ofcom, March 2010.

The overall methodology is summarised in Figure 3.3, although as described below, only certain steps are relevant to the opportunity cost calculations set out in this document:

Figure 3.3: Stages and steps in the calculation of spectrum AIP fees [Source: Ofcom, 2010]



This document is relevant to Steps 1, 2 and 3. If Ofcom decided to impose AIP, our calculations in Step 3 may be used as one of the inputs into Ofcom's calculation of AIP fees in Step 4.

3.3 Approach to the determination of scarcity

The first stage is therefore to establish whether the spectrum in each band is a scarce resource and therefore whether there is a need for Ofcom to calculate a reference rate for the band. We based our decisions on scarcity around three main considerations:

- Is the spectrum currently (or does it seem likely to become) heavily congested under its current own use?
- If the spectrum is not congested, is this due to an artificial limiting factor (for example the restriction of licences)?
- Is there a realistic alternative use of the spectrum, and if so, is there excess demand from any of these alternative uses?

However when assessing scarcity it is necessary for us to consider the demand from 2015 as this is the earliest date that AIP may potentially be applied.

We discuss the results of our analysis for DTT spectrum in Section 4.1 and for DAB spectrum in Section 6.2.

3.4 Approach to the calculation of opportunity costs

If Step 2 concludes there is excess demand for a particular band from both existing and alternative uses, two values need to be calculated to help derive the reference rate for use of the spectrum:

- *the opportunity cost in own use*: this corresponds to the value of the spectrum in its current use
- *the opportunity cost in alternative uses*: this corresponds to the value of the spectrum in other potential uses that appear feasible within a relevant timeframe.

Whilst we understand that no AIP will likely be set if excess demand does not exist, we have in all cases gone on to calculate values in own use in case they are of use to Ofcom.

There are two different approaches to calculate the value in own use and the value in alternative uses: the least-cost alternative (LCA) approach and the discounted profits (DP) approach.[29] Both approaches are summarised in Figure 3.4 below.

Figure 3.4: Summary of the LCA and DP approaches [Source: Analysys Mason, 2012]

	Own use	*Alternative uses*
LCA	For a current average user of the band, the difference between the cost of delivering services using current level of spectrum and the long term least-cost alternative production method following the loss of a small block of spectrum in the band. The user maintains the same level of output	Cost saving that an average provider of an alternative service could achieve if given access to a small block of spectrum in the band
DP	Change in discounted cashflow that an average current user of that band would incur from losing a licence giving access to a block of spectrum from that band. This method may be preferred when it is no longer realistic to assume that output is kept constant.	*Change in discounted cashflow that an average alternative user would generate from holding a licence giving access to a block of spectrum from that band.* *(We do not consider this DP method in our analysis of alternative uses)*

For own use, we calculate the opportunity cost using both methods. However, for alternative uses, Ofcom has asked us to consider only the LCA approach. This is because Ofcom is already undertaking analysis of the value of mobile broadband in the 700MHz band which would be equivalent to a DP approach.

29 LCA is likely to calculate a higher opportunity cost for own use than DP since DP allows spectrum users more flexibility in their response to a loss of spectrum. Conversely, the LCA approach will calculate a lower opportunity cost in alternative use than the DP approach because DP provides the alternative user with greater flexibility in how the spectrum is used and therefore allows for the generation of greater value.

For both the LCA and DP approaches we have built opportunity cost models to calculate discounted free cashflow to perpetuity. We have constructed one model for each type of spectrum usage (e.g. DTT, DAB, mobile) and for each approach to opportunity cost modelling (i.e. LCA and DP).

For both DTT and DAB, there are operators of public service broadcaster (PSB) and commercial (COM) multiplexes (MUX). These operators are the spectrum licensees and our cost models are therefore based at a MUX operator level[30]:

- On the revenue side, the own use models account for any changes in income for commercial MUX operators (e.g. payments for MUX slots); on the PSB side, revenues are likely to be less relevant unless a change in output (i.e. the number of TV stations broadcast and the area covered) were possible.
- On the cost side, we have modelled capital and operational costs, benchmarked against available information on UK broadcast network costs.

We believe it is appropriate to model the operators as they currently exist rather than modelling hypothetical efficient operators, as this allows for calculation of the real opportunity costs.

3.4.1 LCA methodology

Overall approach to the LCA in own use calculation

For the LCA approach in own use, we have considered several possible responses by MUX operators to maintain production levels following a loss of spectrum. These are described in Section 4.2 for DTT and Section 6.3 for DAB. We note that these different responses are not necessarily real options which MUX operators might consider. Rather, they are hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum. In particular we assume in calculating the opportunity costs of DAB and DTT spectrum that any statutory or licensing barriers to MUX operators responding to a (hypothetical) loss of spectrum have been removed.

For both DAB and DTT we compare the cashflow generated by a MUX operator with its existing spectrum holding and with a lower amount of spectrum. The magnitude of the loss of cashflow in the reduced spectrum scenario will differ according to how the operator chooses to respond to the loss of spectrum. However, all possible responses will lead to some degree of cashflow reduction relative to the operator retaining all of its existing spectrum holding.

Our modelling of the opportunity costs assumes that spectrum is lost or gained in indivisible units that are equivalent to the standard spectrum channel widths used at that frequency. DTT spectrum

30 For vertically integrated firms operating MUXs such as Arqiva and the BBC, we focus only on the MUX operator business unit and ignore any incentives and costs brought about through vertical integration.

is therefore modelled as 8MHz channel increments, and DAB spectrum is modelled as 1.5MHz channel increments.

The cashflow is modelled explicitly for 20 years, starting at the beginning of the calendar year 2015 and ending at the end of the calendar year 2034. Beyond this point a terminal value is calculated based on the sum to perpetuity of future cashflow. The start date for the model of 1 January 2015 is chosen to match the earliest date that AIP may be introduced. However, the models include coverage, subscriber, and unit cost information from 2008 onwards to ensure the development from historical numbers can be seen.

The amount by which the cashflow is reduced under the response being considered represents the value of the spectrum to the operator[31]. We express this reduction in cashflow, as a net present value (NPV). Given that our cashflow models begin in 2015 we have expressed all NPV figures in this document in 2015 real terms.

Each model accounts for an appropriate return on capital by using a weighted average cost of capital (WACC) in order to calculate the NPV. The WACC used is based on either a comparable company's regulated WACC (i.e. Arqiva's WACC for DTT and DAB own use), or based on broker reports of companies involved in the same business, as in the case of PMSE.

The calculated NPV is then normalised to a common basis for comparison, by calculating the value per MHz per annum[32]. This normalisation is done by dividing the NPV per MHz by a real-terms annualisation factor, calculated to perpetuity using the operator's WACC and a forecast of inflation[33]. The result is that all normalised (per MHz per annum) values in this document are expressed in 2015 real terms.

By calculating the annualisation to perpetuity, rather than to a fixed period (e.g. 20 years), a more conservative annual opportunity cost per MHz is calculated. This is a slightly different approach to that used for the fixed link AIP for example, where an estimation of the lifetime of the business is used. However, we consider this to be a reasonable approach given that:

- it allows consistent modelling of opportunity costs between services with varying licence length
- it gives an overall conservative opportunity cost to the value of spectrum-loss mitigation costs, as any one-off costs will be spread over a larger period
- the MUX licence terms are long, renewable, and likely to be renewed[34].

This normalisation allows us to compare the costs of different responses to a loss of spectrum by a MUX operator. The lowest of these normalised costs forms the LCA in own use.

31 Specifically it represents the difference in cost of production using the operator's existing spectrum holding and the cost of production using the reduced spectrum holding.

32 To normalise the NPV per annum we calculate an annual cost which, if it were to remain flat in real terms would recover the full NPV including terminal value when summed into perpetuity.

33 The annualisation factor is calculated as 1+(1+inflation)/(WACC-inflation).

34 The MUX licences require renewal every 12 years.

► *Secondary use of interleaved spectrum*

DTT in the UK is delivered over multi-frequency networks (MFNs), resulting in interleaved spectrum being available in geographical areas where certain frequencies are not used by national DTT. This interleaved spectrum is used for PMSE, local TV MUXs and (in the future, possibly) by 'white-space' devices. We note that this complementary use of interleaved spectrum is possible with DTT, but is not necessarily possible if alternative uses (e.g. mobile) use part of the UHF spectrum[35]. This needs to be incorporated into the assessment of opportunity costs associated with each potential use of the spectrum: the value of any secondary use of interleaved spectrum which would be lost under alternative use must be added to the value of primary use when measured against the value in alternative use. In other words, when determining if the value in alternative use is greater than the value in own use, any value in the current secondary use must be added to the current value in primary use if the secondary use is not possible in conjunction with an alternative primary use.

The LCA in alternative use calculation

For the LCA approach in alternative use we have followed a similar approach but instead model the increase in cashflow which could be expected if an alternative use was given access to an amount of the spectrum. The WACC used in this case is the UK mobile operators' regulated WACC for mobile services.

Assumptions and simplifications

In calculating the opportunity cost it is necessary to make the simplification of disregarding 'waterbed' effects. For example it is assumed that when a MUX operator leaves a transmitter site the costs will not increase for the remaining MUX transmitters as a direct result of the operator's move. We note that in practice this cost transfer to the remaining MUXs, or to other services such as DAB[36], may occur to an extent; as such, the actual savings realised by reducing transmitter numbers (e.g. by upgrading to a more efficient technology) may be somewhat lower than those calculated. However we believe this simplification is both required and appropriate given that any second-order cost effects arising from a change in operational strategy would be small, and their calculation highly complex.

We also disregard any contractual difficulties in our calculations. For example, clauses relating to early termination of site usage contracts. We believe this is appropriate for two reasons. Firstly, we assume a four-year duration for managing the switch to an alternative means of providing services (discussed in more detail subsequently). Secondly, we also assume a substantial prior notice period, which would likely allow for a managed exit from the majority of existing contracts.

35 While it may be feasible that these complementary uses could still use the duplex gap in a paired mobile frequency plan, it is considered that practicalities would ensure any value derived from this would be negligible.

36 We note that DAB shares site rental costs with DTT, and therefore a closure of either platform may have a significant knock on effect to the other platform, beyond that considered.

Finally, we do not include the opportunity costs, and any fees which may therefore apply, of using new spectrum when considering responses involving moving to a new band. We note however that such considerations would be included in any business decisions made by an operator on whether to move spectrum band. This reduces possibilities of circular logic in the calculation of opportunity costs.

3.4.2 DP methodology

The DP value (considered only in 'own use') is the difference between the cashflow of delivering a service using the current spectrum and the profit-maximising production method, following the loss of an amount of spectrum, where the same level of output does not need to be maintained. For example if the loss of spectrum makes the current level of service offered commercially unviable this level could be reduced.

As described by the 2005 Indepen/Aegis report[37], the DP method may provide a more realistic view of the opportunity cost than the LCA method, especially in the case of COM MUX operators. It may not be realistic for a DTT MUX operator to maintain the same level of output when one or more channels are removed, and it may be contrary to the commercial interest of an independent MUX operator to undertake a full CPE conversion programme to ensure all users move with the platform in all cases.

Under the DP approach there is a trade-off between the costs incurred by a MUX operator to mitigate the loss of spectrum, and the revenues which might be foregone by not fully mitigating the impact of a loss of spectrum. In other words, if the cost of maintaining output levels after the loss of spectrum would outweigh the revenue benefits of doing so, then the MUX operators may choose not to fully restore output.

The most prominent examples relate to cases where the mitigation for lost spectrum requires an upgrade to CPE (e.g. for a DVB-T2 upgrade of the DTT platform): MUX operators may opt not to provide users with replacement CPE (or to not offer a full subsidy). A MUX operator choosing not to subsidise new STBs may lose a number of end users of DTT. This might imply lower viewing of DTT programmes, with implications for the broadcasters' advertising revenues.

Reduced advertising revenue for TV station providers may reduce willingness to pay for commercial MUX slots[38]. Any reduced payments from broadcasters will be weighed up by MUX operators against the costs of upgrading customer equipment.

Whilst COM MUXs may be able to reduce service levels, or require cost contributions (e.g. purchases of new STBs) from households to minimise (or distribute) the financial impact of a loss

[37] "Study into the potential application of Administered Incentive Pricing to spectrum used for Terrestrial TV & Radio Broadcasting"; Indepen and Aegis on behalf of Ofcom, 2005, See: http://stakeholders.ofcom.org.uk/binaries/consultations/futurepricing/annexes/aipstudy.pdf

[38] We make the assumption that the entire loss of advertising revenue is passed through to the MUX operators, however we note that in practice the exact level of revenue loss passed on will be dependent upon commercial negotiations between the two parties (broadcasters and MUX operators), with the total loss of advertising revenue forming an upper bound.

of spectrum and thus reduce the opportunity cost, the same may not be true for PSB MUXs. PSB MUX operators will be constrained by other factors such as coverage requirements. It will therefore not be feasible to reduce output in response to a loss of spectrum and the same constraints as in the LCA case will, in effect, apply to the PSB MUXs under the DP approach.

3.4.3 Practical considerations

In general, our cost calculations in own use seek to provide cost estimates for different approaches to mitigating a loss of spectrum. With some of these options there may be significant practical difficulties, which we have sought to highlight to Ofcom, and which are discussed further in Section 8.2. It may be that Ofcom considers in some cases that these practical difficulties are insurmountable or that the option is otherwise not viable in practice. If Ofcom were to decide that an option was impractical, one response could be to take the next lowest-cost alternative (or next lowest DP-based cost) as the relevant opportunity cost.

3.5 Frequency of updates to opportunity cost estimates

It is not within the scope of this document to consider how opportunity costs may change over time. However, we note that the relevance of the different spectrum loss mitigation options and underlying demand assumptions may change over time. As such, it may be appropriate to periodically update opportunity cost estimates to reflect these changes.

For example, prior to WRC-06 mobile operators showed little interest in the 700MHz or 800MHz spectrum bands, but the 600MHz band was seen as very valuable for the purpose of rolling out DVB-H networks. Clearly there has been significant change in the thinking of operators since that time and this would have a big impact on an opportunity cost calculation in 2005 compared to one carried out in 2012. The same may be true when looking back on 2012 opportunity cost estimates in, say 2020.

Whilst theoretically the opportunity cost estimates could be regularly adjusted to reflect any changes in market dynamics, this could be a very onerous task.

4 Opportunity cost in own use for DTT spectrum

This section discusses the opportunity cost calculations for the DTT spectrum in own use. The remainder of the section is set out as shown in Figure 4.1 below.

Figure 4.1: Map of Section 4 [Source: Analysys Mason, 2012]

This document focuses on 32 DTT channels, each 8MHz in width, between 470–790MHzexcluding the eight channels between 550–614MHz (the ‘600MHz band’). In our modelling we split the DTT spectrum into three distinct sub-bands: UHF Channels 21 to 30 (470–550MHz), UHF Channels 39 to 49 (614–694MHz); and UHF Channels 49 to 60 (694–790MHz).

Currently this spectrum is used on a primary basis by six national MUXs transmitting on MFNs. Of these, five operate using DVB-T, of which three are COM MUXs and two are PSB MUXs. The sixth is a PSB MUX using DVB-T2 to broadcast in HD.

Currently around 1160 DTT tower sites operate across the UK, of which we classify 53as main sites with transmitters which operate at over 5kW of effective radiated power (ERP). The majority of main sites are shared between commercial and PSB MUXs. Lower-power infill (relay) sites tend to transmit PSB MUXs only in the majority of cases.

We have identified four potential responses by DTT MUX operators to a loss of spectrum from 2015 onwards, and model each of these to find the opportunity cost under both LCA and DP cases. These potential responses are described in Section 4.2 below following an initial analysis on the level of scarcity within the band in Section 4.1.

We note that in the future these options may change and some may no longer be applicable, whilst new options may exist, for example due to technological developments. However, at this point in time, the options listed below are an aid to help us to derive the economic value of the spectrum.

To find the total opportunity cost of the spectrum we need to consider the value both in own use (i.e. the current usage) and in the highest value alternative use. In order to compare like with like, when considering the value in own use we additionally need to consider the value of any interleaved local TV and PMSE services. This is especially relevant when comparing the value in own use with alternative uses such as mobile where the current usage of the geographically interleaved spectrum would no longer be possible.

4.1 Scarcity of DTT primary and interleaved spectrum

In this section we investigate the level of excess demand from both existing and alternative uses in the DTT spectrum bands.

As discussed in Section 3.3, we consider the three main questions for the determination of spectrum scarcity in the DTT bands:

- Is the spectrum currently (or does it seem likely to become) heavily congested under its current own use?
- If the spectrum is not congested, is this due to an artificial limiting factor (for example the restriction of licences)?
- Is there a realistic alternative use of the spectrum, and if so, is there excess demand from any of these alternative uses?

Current own use services consist of DTT MUX broadcasting with both PMSE and (by 2015) local TV services using the spectrum on a secondary interleaved basis. We consider each of these uses in turn below.

4.1.1 Primary use scarcity

Overall we consider there to be excess demand for the primary rights on the spectrum considered, generated both from DTT own use demand and mobile services in alternative use for specific sub-bands.

DTT services

We believe that it would be very difficult to fit an additional DTT MUX into the current amount of available DTT spectrum, especially following the addition of local TV. This suggests that DTT spectrum is currently congested at the national level in terms of the number of MUXs possible. This limits the total number of MUX station slots currently available using current technologies.

We also believe that by 2015 it is likely that sufficient demand for additional MUX slots will exist that, excluding licence and spectrum constraints, an additional MUX operator could profitably enter the market, as we describe below.

Current prices for SD MUX slots indicate a willingness to pay (WTP) of between GBP1 million and GBP3 million per TV station for new slots, which if achievable across each of the 8 new MUX slots, may almost provide sufficient revenues[39]for current MUX operators to consider creating a new MUX[40]. Yet even without demand amongst current players, the business case for an entirely new MUX operator to enter the market may seem attractive, with current MUX operators appearing to make healthy profits.

These arguments indicate that there is likely to be excess demand within DTT own use.

39 A WTP of GBP1–3 million per channel suggests total revenues of GBP8–24 million, if all slot are sold. This compares to a cost of around GBP13 million to run a commercial MUX (excluding administrative overheads which would be shared with existing MUXs), as taken from the SDN accounts.

40 We note that while a spare HD slot currently exists on the BBC-B HD multiplex, this slot is expected to be filled within the next year.

Mobile voice/data services

One of the key alternative uses for the higher-frequency DTT spectrum is likely to be mobile services, including LTE-based high data usage services such as mobile broadband.

The forecast need for additional mobile spectrum within Europe is driven by increasing data traffic levels. This has led to a call for allocation of the 700MHz spectrum band as co-primary for DTT and IMT at the recent WRC-12. If mobile harmonisation occurs within this band, the band is likely to offer significant value to mobile users due to the significant economies of scale gained through the use of an internationally harmonised band.

We also note from Ofcom's recent UHF Strategy Statement that Ofcom intends to allow mobile use of the 700MHz band in place of the current DTT usage.

Conversely, international harmonisation of bands and the resulting economies of scale in handset manufacturing mean that bands which are not internationally harmonised are unlikely to offer much value to mobile operators. Moreover, below 700MHz it is possible that spectrum may be inherently less attractive for public mobile services, potentially requiring the use of larger antennas in devices, which may, to some extent, be less cost-effective. This is one reason why the 614–694MHz band may not be as attractive for mobile use – although we believe that the overriding concern within the mobile industry is international harmonisation in band plans for international mobile telecommunications (IMT) use, which do not currently exist on a large scale below 700MHz[41].

These arguments indicate that (assuming harmonisation occurs) there will be excess demand in the 700MHz band for mobile service but that there is not likely to be excess demand in other bands in the foreseeable future.

Mobile TV services

Previously a case has been made for possible excess demand developing from the future use of the UHF spectrum for DVB-H mobile TV. To date this has not materialised and we do not envisage it occurring within the foreseeable future, given:

- The rise in use of WiFi to offload any excess data requirements arising from video on demand services (such as BBC iPlayer and YouTube), leading to significant growth in these services in a mobile setting.
- The challenges already posed by the number of aerial types that need to be accommodated within mobile devices (though we note that this problem could be overcome at points where the DVB-H forecast is aligned with other countries' mobile frequencies such as the US 700MHz band).

41 We note that spectrum around 450MHz is used for mobile services in some countries, but has not at this stage been widely adopted.

4.1.2 Interleaved use scarcity

Overall we consider there is unlikely to be excess demand for large geographical interleaved spectrum, due to local TV, or for smaller area geographical interleaved spectrum, due to PMSE. We do note however that PMSE could become increasingly squeezed as the supply of suitable spectrum decreases following 800MHz allocation to mobile and the potential allocation 700MHz to mobile in the future. If this were to be the case then conclusions on excess demand for PMSE may need to be re-evaluated.

Local TV services

Recent applications for local TV licences (L-TDPS) showed that in most geographical regions there were multiple applicants for each available licence, in addition to multiple applications to run the local TVMUX. However this apparent excess of demand may reflect the fact that only a single licence was offered in each area, and only one local MUX operator licence was offered for all local TV across the country.

In addition, we note that the profitability of the local TV licences is only ensured by guaranteed subsidy by the BBC (in return for local news items) over the first few years of the TV stations' lifetime.

Without the PSB subsidy and the advantage of a local monopoly, it is unclear whether excess demand would exist for this spectrum. This correlates with the fact that all the local TV MUX applicants relied on BBC funding, and that several of the services were intended to be operated as non-profit organisations.

We do not believe that there is likely to be excess demand[42] for available spectrum if the licence limitation was dropped. We therefore believe that there is insufficient evidence to show scarcity.

PMSE services

In considering scarcity of spectrum for PMSE, we have built on our assessment of excess demand for PMSE from our 2009 report for Ofcom on the *'Opportunity cost and AIP calculations for spectrum proposed for award to a band manager with obligations to PMSE'*[43]. In that report excess demand was determined by considering the following factors by band group:

- whether demand exceeds capacity at infrequent, large events
- whether capacity is lower than demand during the course of day-to-day usage
- the tuning range of equipment
- the increase in assignments.

42 Though we note that potentially London (given its size) could sustain another station.

43 http://stakeholders.ofcom.org.uk/binaries/consultations/bandmanager09/annexes/report2.pdf

In 2009, large growth in assignments and capacity at large events were flagged as potential causes for scarcity in the TV interleaved spectrum band. However, upon examination, scarcity was judged to still not exist in this band.

Between 2008 and 2012, both PMSE assignments and assignment days have fallen in the TV interleaved band as shown in Figure 4.2 below. As a result of this reduction in demand for TV interleaved spectrum for PMSE services we maintain the conclusions of the 2009 Ofcom PMSE report of no excess demand.

	2008	2012
PMSE assignments	72 124	47 798
PMSE assignment days	4 136 199	2 643 800

Figure 4.2: TV interleaved PMSE assignments [Source: JFMG assignment database, 2012]

4.2 Overview of opportunity costs of DTT spectrum in own use

4.2.1 Overall approach

The LCA value in own use is the difference between the cost of delivering the service using the current spectrum and the cost of the LCA production method following the loss of a small block of spectrum in the band, while maintaining the same level of output.

For DTT own use, we define the service level to be maintained as the current number of unique TV stations (including '+1's, radio and HD stations), delivered over the current household coverage areas for both PSB and COM MUXs. This means that if a household is currently receiving only SD (i.e. non-HD) PSB stations, the required minimum level supplied post-mitigation, under LCA, would have to be at least the same set of PSB SD stations. Although we note there may be additional benefit gained if, following the mitigation, this household were to receive additional stations (such as now being able to access the HD TV stations following a DVB-T2 conversion). We have not sought to explicitly quantify any such benefit.

Our DTT modelling considers spectrum loss in increments of 8MHz channels. However, in all cases a mitigation approach would save more spectrum than a single channel. Therefore we divide the calculated opportunity cost by the total spectrum saved rather than only by the bandwidth of a single channel. Additionally, as mentioned in Section 3.4, the values calculated are then converted to an annualised real terms value per MHz, assuming Arqiva's pre-tax nominal WACC of 10.4%[44].

We have identified four potential responses by DTT MUX operators to a loss of spectrum, and have modelled each of these to find the LCA. This is discussed in more detail in Section 4.3.

44 As reviewed in 2010 by Plum Consulting on behalf of the Office of the Adjudicator, see: from http://www.adjudicator-bts.org.uk/documents/plum.pdf

These different responses are not necessarily real options which MUX operators might consider, but rather hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum. For instance, we recognise that MUX operators do not have the right to freely move to using the 600MHz band due to constraints of their licences under the Broadcasting Act. However, in line with other assumptions we do not consider this an impediment when calculating their opportunity cost of the spectrum based on a hypothetical scenario of migrating to use the 600MHz band.

The recent UHF Strategy Statement states that Ofcom intends to allow DTT broadcasting to make use of the 600MHz band in place of the 700MHz band, which is planned to be re-allocated to mobile services at some future point. If this switch were to occur then, subsequently, a migration to the 600MHz band specifically would no longer be a viable response to a loss of spectrum and the lowest cost of the other potential responses (or any new response options which have arisen by that time) may then need to be considered.

The 4 different responses considered are:

- Migration of users from the DTT platform to an alternative platform. We consider Freesat to be the closest alternative as it has a similar range of TV stations, is a non-pay service, and has the ability to provide coverage of approximately the same level as DTT. We do not consider cable or IPTV, as they are unlikely to provide the necessary coverage. While pay-TV services, such as Sky, would provide the stations required, they are highly likely to be more expensive than Freesat in all cases and so are not modelled.

- Implement a technology upgrade to provide increased capacity within the remaining spectrum. We consider the most sensible option to be upgrading of transmission technologies to DVB-T2 (with MPEG-4 compression), as this has already been carried out for the current PSB HD MUX, and is seen as a logical progression.

- Move to an alternative infrastructure for some or all MUXs, e.g. use of an SFN in Channel 36. This would reduce the spectrum requirements but is likely to be practically difficult (due to international coordination) on any frequency other than Channel 36[45]. In addition due to increased guard band requirements, any move to SFN would also entail a DVB-T2 upgrade.

- A migration of up to seven channels to the 600MHz band (UHF Channels 31-37). Whilst not reducing the spectrum usage overall, a move to the 600MHz band would free space in the current DTT bands. This option has already been considered by Arqiva[46] and in Ofcom's UHF Strategy Statement as a potential solution to a loss of spectrum for DTT in the 700MHz band.

While a possible additional alternative could be to invest in infrastructure to compensate for coverage loss (e.g. in-fill sites), this would lead to a considerably higher infrastructure cost, and as

45 Channel 36 is already reasonably well internationally coordinated due to its historical use for long range aeronautical radar. It also is currently not used for any specific purpose.

46 See http://stakeholders.ofcom.org.uk/binaries/consultations/uhf-strategy/arqiva.pdf

such it was felt that this option could immediately be ruled out as it would not provide a lower opportunity cost approach for either LCA or DP methodologies.

It is acknowledged that many of these spectrum loss mitigation responses may require significant levels of work by Ofcom, MUX operators and potentially others to engage in frequency re-planning with neighbouring countries to optimise frequency packing under the new network design.

As a general point, it is assumed that PSB and COM MUX operators will coordinate to address the impact of any spectrum loss, for any scenario where an ‘all jump together’ approach would provide a more efficient alternative to acting independently (e.g. an upgrade of the entire platform to use DVB-T2).

Some of the alternatives require a replacement of certain CPE or receiving aerials. Where the replacement of CPE or aerials forms a part of the response, a scenario-based approach has been used to find the cost under four different replacement scenarios.

- CPE replacement Scenario1: Replacements only for the primary DTT-only TV set in any household
- CPE replacement Scenario2: Replacements for any primary or secondary DTT-only TV set in any household
- CPE replacement Scenario3: Replacements for any DTT-only TV set in any household
- CPE replacement Scenario4: Replacements for every DTT-only TV and any TV that has an integrated DTT receiver (whether this set is only used for DTT or not).

We consider Scenario 1 to be most likely and mainly focus on results from this scenario in forming our conclusions. We refer to these four scenarios collectively as the CPE replacement scenarios.

4.2.2 PSB and COM MUXs

For DTT spectrum in own use, we have distinguished between the opportunity cost for PSB MUXs and COM MUXs. This is due to the differences between the networks and services offered by the PSB and COM MUXs, which can be summarised as:

- one PSB MUX transmits HD stations on MFN using DVB-T2;all other MUXs (i.e. all COM MUXs and two PSB MUXs) transmit in SD using DVB-T
- the stations broadcast on the PSB MUXs vary according to region whereas the COM MUXs broadcast a uniform set of stations to all regions
- PSB MUXs offer coverage to a wider area than COM MUXs, and consequently use a much more extensive network of sites.

In order to calculate the difference in opportunity costs of PSB and commercial MUX operators, we have in some cases had to calculate the total cost and then split it equitably between the two groupings. One major example of this is in relation to household CPE conversion, the costs of which are allocated between PSB and COM MUXs based on their respective coverage. COM

MUXs provide around 90% coverage, so 90% of the costs are split equally between all six MUXs resulting in a share of around 15% of costs allocated to each. The PSB MUXs provide c. 98.5% coverage and so additional costs due to this extra8.5% of coverage are split between the three PSB MUXs only, taking their share of the total costs to around 18%. This difference in coverage is (inaccurately) illustrated in Figure 4.3 below.

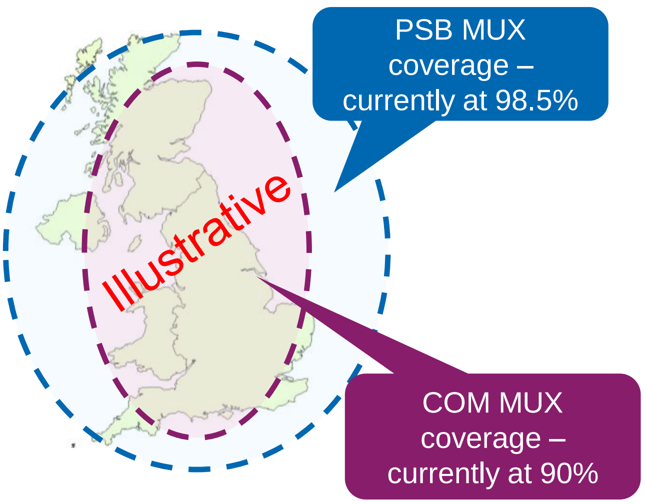


Figure 4.3: Illustrative coverage levels for PSB and COM MUXs [Source: Analysys Mason, 2012]

For sites and transmitters, any costs are allocated by costing the actual number of PSB and COM sites requiring modification. As the PSB MUXs have significantly more infill sites than the COM sites, PSB MUXs take a far higher proportion of site modification costs. However we note that these costs only make up a minority of the total costs, which are dominated by replacement CPE and receiver aerials[47] for the majority of mitigation responses.

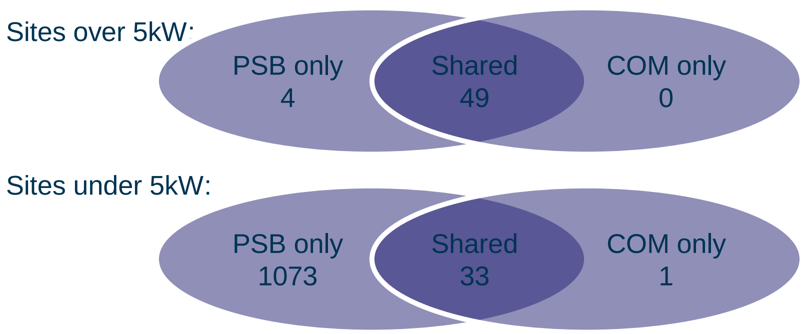


Figure 4.4: Site split between PSB and COM MUXs [Source: Analysys Mason, 2012]

Any cost items that are not directly service-related are assumed to be split evenly between MUX operators. For example, in moving a single MUX to an SFN, it makes sense for a COM MUX to be moved due to the lower costs incurred. However, the costs of doing this are assumed to be split evenly between the PSB and COM MUX operators.

47 The cost of CPE replacement and replacing receiver aerials are both split between PSB and COM MUXs in the way described above.

4.2.3 Market sizing

It is necessary to quantify the number of CPE replacements required for each of the four CPE replacement scenarios discussed above, and across the different mitigation responses. To do this we have developed a market model which forecasts the number of TV sets and their usage throughout the UK, as shown in Figure 4.5.

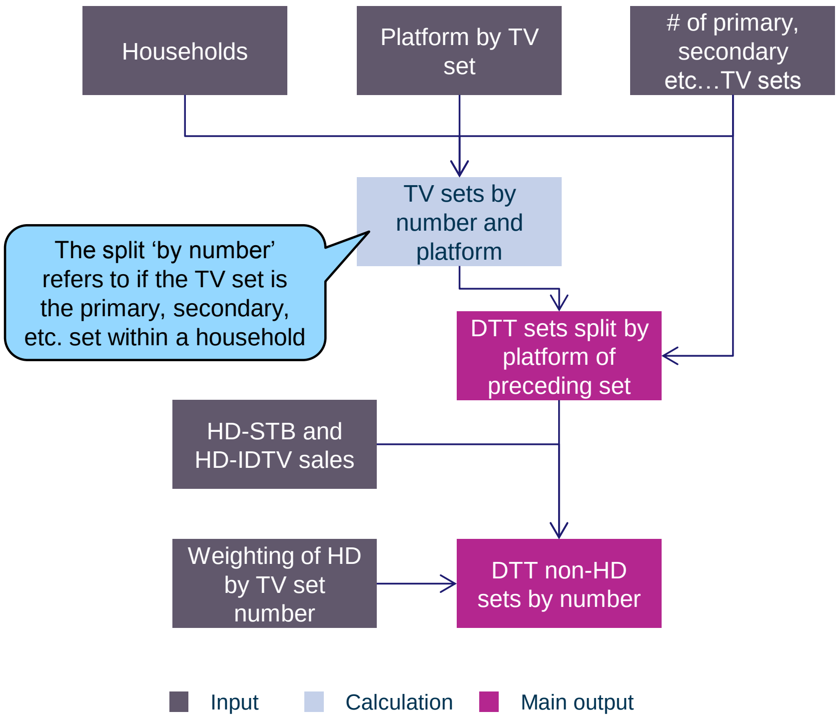


Figure 4.5: Flow diagram of the DTT CPE and TV usage market model [Source: Analysys Mason, 2012]

The number of households in the UK is calculated and split between houses and flats, using historical and forecast data from the Department for Communities and Local Government.

The number of TV sets per household is calculated based on an update of the percentage of households with 1, 2, 3 or 4+ TV sets from Ofcom's 2004 Communications Market report[48]. The platform used on each of these TV sets is taken from Ofcom's 2011 and 2012 Communications Market reports.[49]

Any non-primary DTT-only TV sets are divided into those where the household has DTH, cable, or DTT on a preceding set. It is assumed that cable or DTH primary set households will use either the same technology service, or use DTT, on later sets. We consider this to be sensible given the level of savings from 'multi-room' deals and additional administrative effort required to have multiple pay services from different retailers.

48 See http://stakeholders.ofcom.org.uk/market-data-research/market-data/communications-market-reports/cmpdf/

49 See http://stakeholders.ofcom.org.uk/market-data-research/market-data/communications-market-reports/?a=0

This means, for example, that the number of DTT secondary sets in households which use DTH/cable on their primary set is modelled as the minimum of:

- the number of DTT secondary sets split by the platform share of DTH/cable on primary sets, for example if 40% of primary sets were cable we assume that no more than 40% of DTT secondary sets were preceded by a cable primary set.
- the difference in the number of primary DTH/cable sets and the number of secondary DTH/cable sets (as this is the maximum number of sets that could have moved from DTH/cable to DTT), for example if 4 million primary sets were cable but only 3 million secondary sets were cable, we would know that no more than 1 million DTT secondary sets could be preceded by a cable primary set.[50]

The number of HD sets in the market is calculated using a forecast extrapolating Ofcom data on historical sales of HD-STBs and HD integrated digital televisions (IDTV). These HD sets are split between primary and other household sets based on figures in the Ofcom 2012 Communications Market Report. We assume, in line with a previous forecast by Zetacast[51], that 90% of primary DTT sets will be HD capable by 2020.[52]

4.2.4 DP subscriber loss calculation methodology

As discussed in Section 3.4.2, the opportunity cost of the DTT spectrum under the DP approach is calculated as the amount that a MUX operator would be prepared to pay to retain its spectrum (or more precisely, the amount that MUX operators would be prepared to pay to retain a small amount of their spectrum, scaled up across all DTT spectrum). This differs from the LCA approach in that the same service levels do not necessarily have to be maintained if spectrum were to be lost.

The MUX operator is therefore able to follow a production method and strategy that will minimise its loss of profit. For own use, the DP approach will therefore generate an opportunity cost that is lower than or equal to the LCA approach.

To model this DP opportunity cost we use a similar approach as for the modelling of the LCA opportunity cost. That is, we evaluate the cost under several different spectrum loss mitigation options. However, under the DP approach we also allow the COM MUX operators to provide CPE and replacement aerial subsidies only where it is profitable to do so, and quantify the consequent benefit to the overall cost of mitigation. We also consider the impact of the fall in the DTT platform's viewer numbers caused by this approach, and the consequent loss of advertising revenue for broadcasters. We assume that the MUX operators would then experience a proportional reduction in revenues due to a reduced demand for MUX slots by broadcasters.

50 It is not possible to use the difference in cable sets (i.e. 1 million) to find the exact level of DTT sets preceded by cable as part of these households may not have any secondary set.

51 http://stakeholders.ofcom.org.uk/binaries/consultations/uhf-strategy/zetacast.pdf

52 Note that this assumes that no loss of DTT spectrum and DVB-T2 upgrade, or other mitigation approach, has occurred.

Because one of the largest factors in the majority of the LCA mitigation responses is the cost of CPE and aerial replacements, we consider this to be the main area where MUX operators are likely to consider reducing service levels, and hence save costs. We have modelled this by assuming that operators are able to offer a subsidy rather than a full replacement of equipment. A subsidy of 100% relates to full replacement of CPE (equivalent to the assumptions in under the LCA approach) and a subsidy of 0% relates to the consumer having to replace their own CPE with no help from the MUX operator.

It is assumed that if the consumer has to spend their own money to mitigate a loss of service, they will make a rational decision as to whether they wish to incur this cost and stay on the DTT platform. Alternatively the consumer could move to a substitute service, such as Freesat. To assess the trade-off between subsidy level (and the resultant costs) and the number of subscribers who leave the platform (and the resultant costs), we analyse demand curves. These demand curves reveal user preferences for ‘DTT versus no service’ and ‘DTT versus competitive platforms’ (i.e. Freesat and pay TV).

These demand curves are used to calculate the number of viewers migrating to alternative platforms at a particular incremental price of remaining on the DTT platform (i.e. the unsubsidised portion of the CPE replacement cost). These numbers of viewers were derived for Freesat and for pay TV platforms based on WTP data taken from various Ofcom reports. To aid the construction of these curves, Sky’s basic TV package was used as a proxy for all pay TV.

The incremental price of switching platforms for a DTT viewer is directly related to the amount of subsidy provided by the MUX operator. The cost of switching to another platform would appear incrementally cheaper to viewers where lower subsidy is offered to stay on DTT. To calculate the incremental costs we amortise all upfront CPE costs (both for staying on the DTT platform and for moving to Freesat or a pay TV platform) over a period of one year. It is assumed that the incremental costs are based on buying a new basic STB to provide access to a TV service, rather than the costs of also replacing any personal video recorder or internet connection services which the household’s previous STB may have been capable of. All incremental costs are calculated in real 2012 prices, with demand curves also transferred to real 2012 prices for consistency.

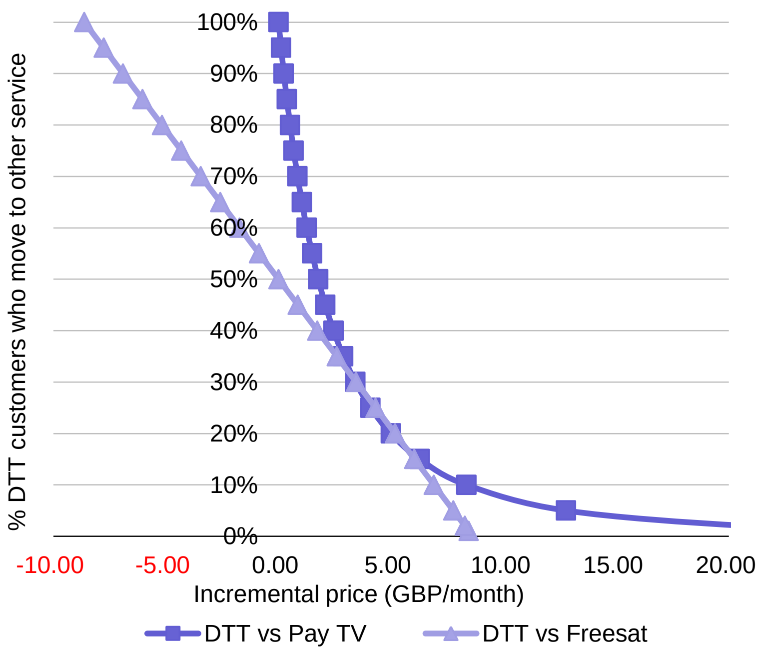


Figure 4.6: Demand curve for alternative platforms (Freesat and Pay-TV), real 2012 prices[Source: Analysys Mason, 2012 and 'Pay-TV consultation – Annex 10', Ofcom, 2008]

As users can switch to either Freesat or to a pay-TV platform, and numbers moving to both are calculated independently, there is potential of double counting the number of people moving away from the DTT platform. To reduce this effect we have assumed a 40% reduction in the smaller group of leavers to either Freesat or pay TV, to account for this potential overlap.

We also consider the number of users who would no longer take any TV service (e.g. switch to just DVDs or use iPlayer only) when faced with an incremental cost of remaining on DTT.

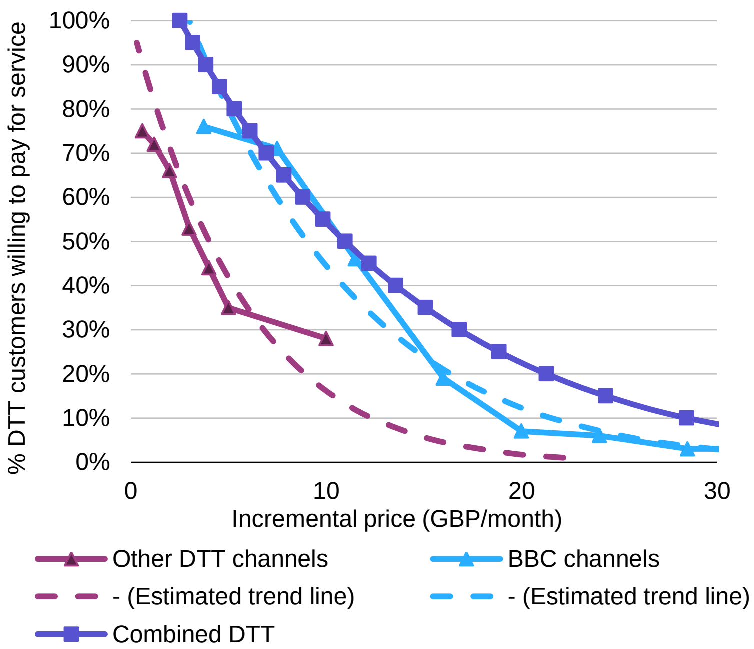


Figure 4.7: Demand curve for DTT channels, real 2012 prices [Source: Analysys Mason, 2012 and 'Assessing the value of public service programming on ITV1, Channel 4 and Five', Holden Pearmain on behalf of Ofcom, 2008]

The total revenue lost by MUX operators is assumed to be equivalent to the amount of advertising revenue lost by the TV station providers (i.e. broadcasters). This is due to the assumption that the entire loss of advertising revenue is passed through to the MUX operator through reduced MUX slot demand and therefore reduced MUX slot prices.

An assumption is made that advertising revenues are generally allocated between viewing platforms on the basis of the principal (primary) TV set within each household. As such the advertising revenue lost is calculated as the percentage of the total primary DTT households that are lost to other platforms multiplied by the total DTT platform advertising revenues.

The assumption that only primary household TVs are considered in the advertising loss means that the maximum DP subsidy would be that under LCA CPE replacement Scenario 1. No subsidy is provided to households beyond that for the first TV set, as there is no financial benefit in doing so.

To find the minimum mitigation cost under the DP methodology, we test different subsidy levels at 5% increments to find the optimal subsidy level at which the combined costs, from both CPE subsidy and MUX revenue loss, are minimised.

4.3 DTT spectrum in own use LCA and DP opportunity costs

In this section we consider in turn each of the four potential responses to a loss of DTT spectrum which we have identified, under both the LCA and DP methodologies.

4.3.1 Switch of the whole DTT platform to Freesat

LCA approach

The cost of moving the whole DTT platform to Freesat under the LCA case is determined by four key drivers:

- the (CPE) cost of household conversion from DTT to Freesat
- the costs associated with publicity relating to the switch
- the savings made from avoiding future operating costs of the DTT platform
- the loss of future DTT revenues for MUX slots.

The cost of household conversion is calculated using the number of DTT sets that require replacement (determined by the CPE replacement scenario considered) multiplied by the unit CPE costs. This is added to the cost for marketing/raising awareness of the platform shutdown which is based on the equivalent TV DSO costs of running Digital UK.

The cost of converting a household is dependent on the amount of work/equipment required to provide and install the replacement CPE. In our modelling this is varied depending on whether the TV set is the household’s primary or non-primary set, the other platforms already available in the household, and if the household is a house or a flat.

Where a primary DTT set conversion is modelled, costs are included for a dish, an STB, cabling time and installation of the dish (which is increased slightly in the case of flats). However where non-primary DTT sets require conversion, the costs modelled depend on the platform of the primary household set:

- if the primary household set has DTH, only STB and cabling installation costs are required
- if the primary household set has cable, then a full conversion is required, as for the primary DTT set
- if the primary household set has DTT, the set only requires an additional STB and it is assumed that all necessary cabling is installed when the preceding DTT set is converted (which occurs in all CPE replacement scenarios).

All unit costs for CPE are taken from current retail price lists with costs forecast using an expected 2% per annum reduction in the nominal price of electronic equipment. The cost of dish installation is estimated using an average install time multiplied by an average installation engineer’s salary. We note that we are only intending to provide a basic broadcast receiver, and any additional subsidy requirements to replace additional CPE services (such as STBs with inbuilt personal video recorder or internet connection) would push the opportunity cost higher.

Given the CPE costs of migration to Freesat, the large amount of fixed costs in DTT transmission, and the small incremental cost of moving additional MUXs beyond the first, the MUX operators would logically move to close the whole DTT platform if the Freesat option were to be considered. This would mean that the MUX operators would save all MUX transmission and distribution costs, but additionally lose all future revenue generated from transmitting TV stations.

These future revenues have been estimated for both PSB and COM MUXs using a similar methodology to the original Indepen/Aegis report. Where possible the transmission costs and revenues were updated using the average of the costs and revenues taken from the SDN and Digital 3&4 annual accounts. These were then multiplied up by the number of MUXs to find the total cost and revenue.

The total spectrum released from closing the DTT platform would be 256MHz, i.e. each MUX (both PSB and COM) is assumed to release 43MHz.

The overall calculation flow is illustrated in Figure 4.8 below.

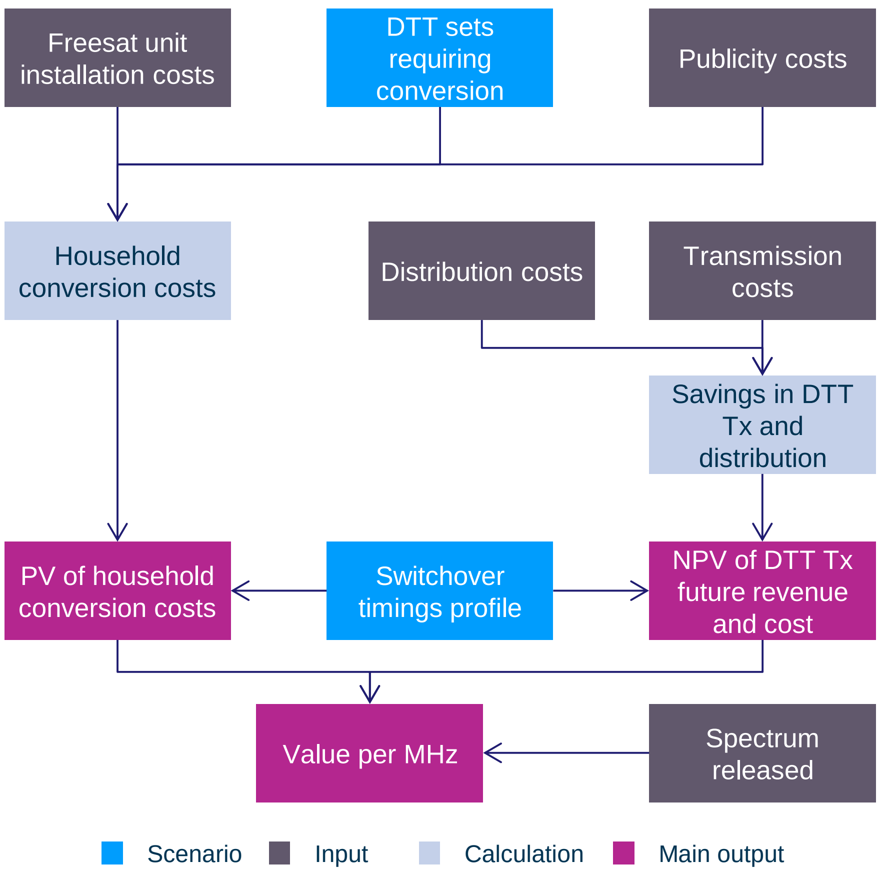


Figure 4.8: Flow diagram of the Freesat LCA methodology [Source: Analysys Mason, 2012]

The costs of this response under the LCA methodology are shown below in Figure 4.9, with two potential lengths of switchover period compared[53]. As will be seen, under the LCA methodology, the move of the platform to Freesat gives the highest cost in our range of potential spectrum loss mitigation responses.

The longer switchover period gives a smaller opportunity cost valuation than the single-year switchover (with both switchover timeframe's being based on a 2015 start date). We consider that a four-year conversion period (more in line with TV DSO) is more appropriate for our base case, and so this is the basis on which we subsequently compare all the spectrum loss mitigation responses in this document.

We also note that the main reason for the reduced opportunity cost for the longer switchover period is actually that the profitable business of a MUX operator can be continued for an additional 3 years.

53 The 1 year switchover is consistent with the original Aegis-Indepen report.

Figure 4.9: Costs for the switch to Freesat LCA (CPE replacement Scenarios 1-4) [Source: Analysys Mason, 2012]

	Total (GBP thousand/MHz/annum)	Per PSB (GBP thousand/MHz/annum)	Per COM (GBP thousand/MHz/annum)
1 year switch	1383–2345	1435–2480	1331–2210
4 year switch	1238–2066	1283–2182	1193–1950

We consider a four-year switchover period and CPE replacement Scenario 1 to be the most likely combination. A further breakdown of the cost drivers, given for this scenario is shown below in Figure 4.10.

Figure 4.10: Net present value breakdown into cost categories for LCA, CPE replacement Scenario 1, for the platform switch to Freesat [Source: Analysys Mason, 2012]

NPV categories	Total (GBP thousand)	Per PSB (GBP thousand)	Per COM (GBP thousand)
Cost of household conversion	1 710 485	309 682	260 480
DTT future costs	-1 475 334	-245 889	-245 889
DTT future revenues	4 044 174	674 029	674 029
Costs associated with publicity	148 717	26 925	22 647
Total	**4 428 042**	**764 747**	**711 267**
Spectrum released	256.0MHz	42.7MHz	42.7MHz
Value/MHz/Annum	**1238**	**1283**	**1193**

DP approach

For our modelled move of the DTT platform to Freesat, it is clear that the optimal strategy for a commercial MUX operator is to not provide any subsidy for CPE equipment for moving to Freesat. This is because following switch-off of the DTT platform there is no opportunity to derive further revenues from subscribers from the MUX operators' perspective.

This strategy would reduce the CPE replacement costs to zero, meaning that, unlike in the LCA case, fewer synergies are received if MUXs operate together by turning off the entire platform. Therefore while one option may remain to turn off the whole platform, it is also possible that only a single MUX could be removed from DTT. It is also possible that with only one MUX turned off, the remaining MUX slots may gain some additional value through increased competition for slots. While it is very difficult to exactly quantify the size of this effect, we have shown the impact for an increase of 10% and 20% on remaining MUX slot prices below in Figure 4.11.

Figure 4.11: Results for Freesat DP scenarios for commercial operator [Source: Analysys Mason, 2012]

Mitigation strategy	No MUX slot price increase (GBP thousand/MHz/annum)	Increase of 10% for remaining MUX slots (GBP thousand /MHz/annum)	Increase of 20% for remaining MUX slots (GBP thousand /MHz/annum)
Whole platform is moved to DTH	718	N/A	N/A
DP cost of single MUX moved to DTH	735	585	435

As would be expected, even a 20% price rise in the other MUXs slots (which is likely far higher than what would be seen in practice) does not make up for the lost revenues following the MUX closure, though it does significantly reduce the overall mitigation cost.

A further breakdown of the mitigation costs is shown below in Figure 4.12.

Figure 4.12: Net present value breakdown into key factors for DP, for the switch to Freesat [Source: Analysys Mason, 2012]

NPV categories	Whole platform moved - No MUX slot price increase (GBP thousand)	Single MUX moved - Increase of 10% for remaining MUX slots (GBP thousand)	Single MUX moved - Increase of 20% for remaining MUX slots (GBP thousand)
Cost of household conversion	0	0	0
DTT future costs	-1 475 334	-235 784	-235 784
DTT price raise	0	-89 556	-179 113
DTT future revenues	4 044 174	674 029	674 029
Costs associated with publicity	0	0	0
Total	**2568840**	**348 688**	**259 132**
Spectrum released	256.0MHz	42.7MHz	42.7MHz
Value/MHz/Annum	**718**	**585**	**435**

4.3.2 Upgrade of all MUXs to broadcasting using DVB-T2 (and MPEG-4) technology

Currently UK DTT services operate using two separate transmission specifications, DVB-T and its technological upgrade, DVB-T2. Although both specifications operate via coded orthogonal frequency division multiplex (COFDM), the DVB-T specification uses MPEG-2 video and MPEG-1 Audio Layer II (MP2) codecs, whereas DVB-T2 uses MPEG-4 advanced video coding compression. While it is possible to upgrade the transmission specification separately from the compression method, both upgrades require an upgrade of consumer equipment, in the form of an STB or digital TV receiver, making it more sensible to conduct the upgrades simultaneously.

Given that DVB-T2 is able to achieve a maximum data rate almost double that of DVB-T[54] and a change to MPEG-4 allows programme data to be compressed by an additional 33%, one possible spectrum mitigation solution, as per the LCA analysis, would be to move the five remaining DVB-T MUXs over to DVB-T2 and MPEG-4, and therefore reduce the number of MUXs required.

A full-scale change to DVB-T2 MPEG-4 would require all existing DVB-T MPEG-2 receivers to be replaced. However, since both services have been running simultaneously for several years a proportion of homes have already upgraded to DVB-T2 receivers and would not require further migration.

LCA approach

The cost of upgrading the whole DTT platform to DVB-T2 under the LCA case is determined by 5 key drivers:

- the costs of household CPE conversion from DVB-T to DVB-T2 and the cost of domestic aerial changes resulting from rearrangement of the spectrum
- the costs of re-engineering transmitters and re-engineering transmitter aerials
- the costs of frequency re-planning to fully vacate the saved spectrum
- the costs associated with publicity of the technology upgrade
- the savings made from reducing future DTT transmission costs.

The methodology for calculating the opportunity cost of an upgrade of existing DTT CPE to DVB-T2 technology is similar to that used for satellite migration, and uses the same TV set and household assumptions and scenarios from our market model. CPE costs are incurred when replacing existing DVB-T STBs with DVB-T2/MPEG4-compatible STBs. However, it is assumed that any set which is already HD capable (by STB or integrated receiver) does not require further conversion. This means that as the number of pre-deployed HD-capable equipment increases over time the DVB-T2 conversion cost drops.

In order to fully vacate the saved spectrum, and free a contiguous spectrum block, it is necessary for the remaining MUX operators to undergo a full re-planning process. We note this is likely to take a significant amount of time, and due to international coordination issues may be non-trivial to complete. This re-planning not only has a direct cost associated with it but will also mean that a proportion of the UKs aerials may be moved out of group and so require replacement.

The number of aerials that go out of group is dictated by the frequencies in which the contiguous block is formed – and hence the opportunity cost for vacating spectrum varies between each of our three DTT sub-bands modelled. As such we have calculated opportunity costs for each of the three DTT sub-bands separately.

54 47.8Mbit/s compared to 29Mbit/s, though currently DVB-T2 within the UK runs at 39.2Mbit/s (extended up to 40.2Mbit/s for certain modes). See http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-policy-area/projects/dtv/g-bensberg-letter-dvb-t2.pdf

In addition to CPE costs, there are costs associated with network re-engineering due to a requirement for additional DVB-T2 modulators at operators' sites[55] and DVB-T2 gateways at the MUX central headends.

With a total required data capacity of 167Mbit/s (2×24.1Mbit/s, 3×27.1Mbit/s and 1×40.2Mbit/s), only four MUXs are required after moving to DVB-T2/MPEG-4, given a 40.2Mbit/s data rate (per MUX) and the addition of an improvement in compression ratio by a factor of 3/2. This means that two MUXs worth of non-fixed transmission costs are also saved, where these were estimated as a proportion of a MUX operator's reported costs.[56] The total spectrum vacated assuming a successful re-planning is 80MHz. The overall calculation flow is illustrated in Figure 4.13 below.

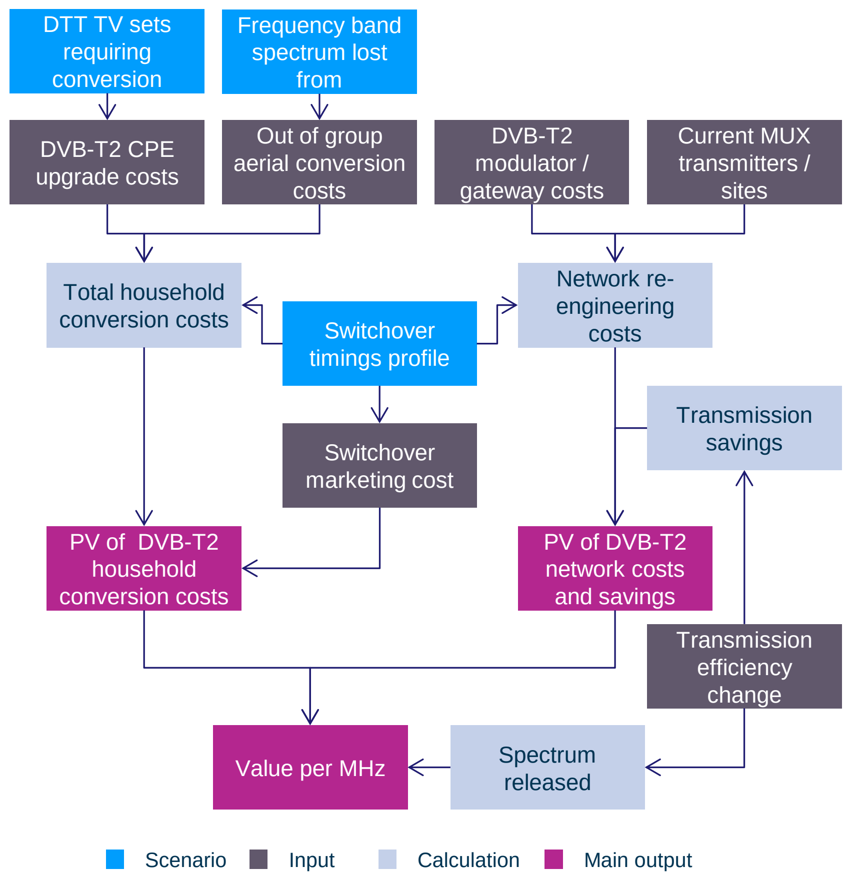


Figure 4.13: Flow diagram of the DVB-T2 upgrade LCA methodology [Source: Analysys Mason, 2012]

As with satellite migration, all costs related to household conversion are split between PSB and COM MUXs using the MUX coverage factors. However although the costs for the existing DVB-T2 PSB MUX would be very low, we believe it appropriate to allocate the costs evenly between all 6 PSB and COM MUXs within COM coverage areas, and between all 3 PSB MUXs outside of the COM coverage.

Consistent with this, all site and transmitter costs are allocated by costing the actual number of PSB and COM sites requiring modification, and for PSB costs again splitting them between the 3

55 The number of sites requiring retuning again slightly varies depending on the frequencies cleared.

56 The proportion of SDN Limited (the operator the commercial MUX A) costs saved was estimated using the proportion of Arqiva's TV costs which are assumed to be variable.

MUXs. As the PSB MUXs have significantly more infill sites than the COM MUXs, PSB MUXs take a far higher proportion of site modification costs. However, these costs still only form a minority of the total costs, which are dominated by the replacement STBs and receiver aerials.

As previously, the DVB-T2 upgrade model also assumes a 4-year period for switchover, starting in 2015, with the results split by sub-band and by PSB and COM MUX shown below in Figure 4.14.

Figure 4.14: LCA cost for DVB-T2 technology upgrade (CPE replacement Scenarios 1-4) [Source: Analysys Mason, 2012]

	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
Total	532–1632	394–1361	413–1399
Per PSB	580–1775	430–1481	450–1521
Per COM	484–1490	358–1242	376–1276

We note that given the high proportion of the total costs made up from CPE and receiver aerial replacement costs, the change in results between CPE replacement Scenario 1 (only primary CPE/aerials replaced) and CPE replacement Scenario 4 (all equipment replaced even if not used by DTT) is dramatic. While the exact opportunity cost would therefore depend heavily on the equipment replacement approach taken at the time of spectrum loss, we believe that CPE replacement Scenario 1 represents the most likely outcome (as it is in line with TV DSO policy).

A breakdown of the total costs calculated for CPE replacement Scenario 1 is shown in Figure 4.15 below.

Figure 4.15: Net present value breakdown into cost categories for LCA, for the upgrade of all DTT MUXs to DVB-T2 [Source: Analysys Mason, 2012]

NPV categories	Channels 21 to 30 (GBP thousand)	Channels 39 to 48 (GBP thousand)	Channels 49 to 60 (GBP thousand)
Cost of replacement CPE	84 056	84 056	84 056
Costs of domestic aerial changes	372 109	217 849	239 102
Costs of re-engineering TXs	925	925	925
Costs of re-engineering TX aerials	2036	1924	1774
Costs of re-planning	418	418	418
Costs associated with publicity	148 717	148 717	148 717
Loss (/savings) from transmission	-13 304	-13 304	-13 304
Total	**594 957**	**440 585**	**461 687**
Spectrum released	80.0MHz	80.0MHz	80.0MHz
Value/MHz/Annum	**532**	**394**	**413**

DP approach

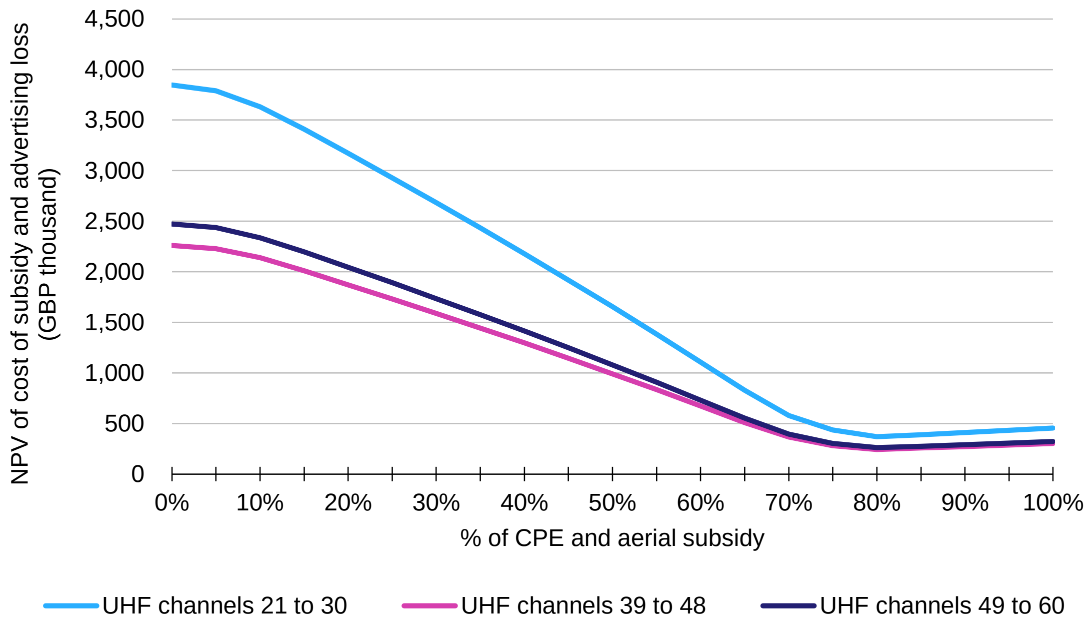
As discussed previously, it is assumed that the DP approach is always incremental to CPE replacement Scenario 1 under the LCA approach. As such the DP costs below in Figure 4.16are only given for CPE replacement Scenario 1.

Figure 4.16: DP cost for DVB-T2 technology upgrade (Scenario 1) [Source: Analysys Mason, 2012]

	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
Total	454	342	357
Per PSB	491	371	387
Per COM	416	313	327

In the DVB-T2 upgrade DP case, an optimal CPE subsidy of around 80% is calculated and applied in the results above. As the incremental costs of staying on the platform are relatively high, a lower subsidy would result in a significant loss in subscribers and therefore advertising revenues. The exact trade-off between these two costs relative to the subsidy given is shown below in Figure 4.17 for each of the three DTT sub-bands.

Figure 4.17: NPV optimisation for DP method upgrade to DVB-T2 [Source: Analysys Mason, 2012]



The costs for vacating UHF Channels 21 to 30 are significantly higher than for other sub-bands because transmission has to move to Channel 39 or above, which is above the frequency range covered by Group A aerials, which serve the majority of households in this frequency band. This also means the potential customers who could move off of the platform is much higher hence the high NPV at 0% subsidy. A full description of the aerial replacement calculations can be found in Annex A.

A further breakdown of the total costs of the DVB-T2 upgrade response under the DP approach for CPE replacement Scenario 1 is shown below in Figure 4.18.

Figure 4.18: Net present value breakdown into cost categories for DP, for the upgrade of all DTT MUXs to DVB-T2 [Source: Analysys Mason, 2012]

NPV categories	Channels 21 to 30 (GBP thousand)	Channels 39 to 48 (GBP thousand)	Channels 49 to 60 (GBP thousand)
Cost of replacement CPE	67 232	67 237	67 236
Costs of domestic aerial changes	297 630	174 260	191 258
Costs of re-engineering TXs	925	925	925
Costs of re-engineering TX aerials	2036	1924	1774
Costs of re-planning	418	418	418
Costs associated with publicity	148 717	148 717	148 717
Loss from advertising	3634	2128	2335
Loss (/savings) from transmission	-13 304	-13 304	-13 304
Total	**507 289**	**382 305**	**399 359**
Spectrum released	80.0MHz	80.0MHz	80.0MHz
Value/MHz/Annum	**454**	**342**	**357**

4.3.3 Change of single MUX to SFN andDVB-T2 upgrade across all MUXs

The possible spectrum loss mitigation response of moving a single MUX to an SFN network on Channel 36, requires initially for the platform to be upgraded to DVB-T2 (as described above in Section4.2) in order to achieve the required coverage levels. The requirement of this upgrade stems from the fact that DVB-T2 permits the use of the existing high-power transmitter locations. Although an SFN would be possible with DVB-T, the characteristics of the older standard mean that the network will be more constrained by self-interference, requiring the use of a larger number of lower-power infill sites which would be prohibitively expensive. The increased size of transmitting cells with DVB-T2, specifically when used for an SFN, comes from the possibility of increased guard intervals when using DVB-T2, allowing for larger discrepancies in signal timing and hence larger distances before the signals from competing sites begin to interfere.

It is proposed to use Channel 36 for the SFN as, due to historical reasons[57], it would be relatively easy to internationally coordinate. Using Channel 36 may still require a trade-off in terms of surrender of rights on other parts of the spectrum, though this would be dependent on the outcome of negotiations.

The use of DVB-T2 to increase guard intervals in this fashion reduces the capacity of the MUXs when compared to the DVB-T2 run in MFN (as discussed above). The minimum number of

[57] This band was historically kept clear for Radar in Jersey. In recent years the channel was intended for DVB-H use, flowing this however Ofcom stated they planned to auction it with rest of 600MHz band. We have assumed an SFN would be placed here following Ofcom's suggestion.

MUXs required would still be 4, though less spare capacity would exist when compared to the LCA approach described above[58].

LCA approach

The opportunity cost of moving a single MUX to an SFN, and upgrading the DTT platform to DVB-T2, is determined by 6 key drivers under the LCA case:

- the costs of household CPE conversion from DVB-T to DVB-T2 and the cost of domestic aerial changes resulting from rearrangement of the spectrum
- the cost of re-engineering transmitters and re-engineering transmitter aerials
- the costs of frequency re-planning to fully vacate the saved spectrum
- the costs associated with publicity of the technology upgrade
- the potential cost of additional infill sites
- the savings made from reducing future DTT transmission costs.

Overall the same TV set and household assumptions and scenarios from our market model are used as in the DVB-T2 upgrade and move to Freesat models.

The addition of the SFN in Channel 36 to the response results in some incremental costs, but also allows the MUX operators to save an additional 40MHz of spectrum.

It is assumed that a COM MUX is moved to an SFN, as this reduces the number of aerial and site retuning required due to the smaller coverage area, while also potentially decreasing any issues with international coordination given the lower levels of transmission spreading internationally.

Due to the move to DVB-T2, only four MUXs are required following spectrum mitigation. In addition any aerials/sites retuned for the DVB-T2 move are assumed to be set to the appropriate channel including the SFN (rather than needing to be retuned twice). However, moving one MUX to SFN causes some transmitters that were not re-tuned in the move to DVB-T2 to now need retuning. This will cause some receiver aerials that were still in group following the DVB-T2 frequency reorganisation to also require replacing.

The overall calculation flow is illustrated in Figure 4.19 below.

58 As we have not considered any potential gain from an increase in spare capacity above we do not consider any reduction in this capacity here.

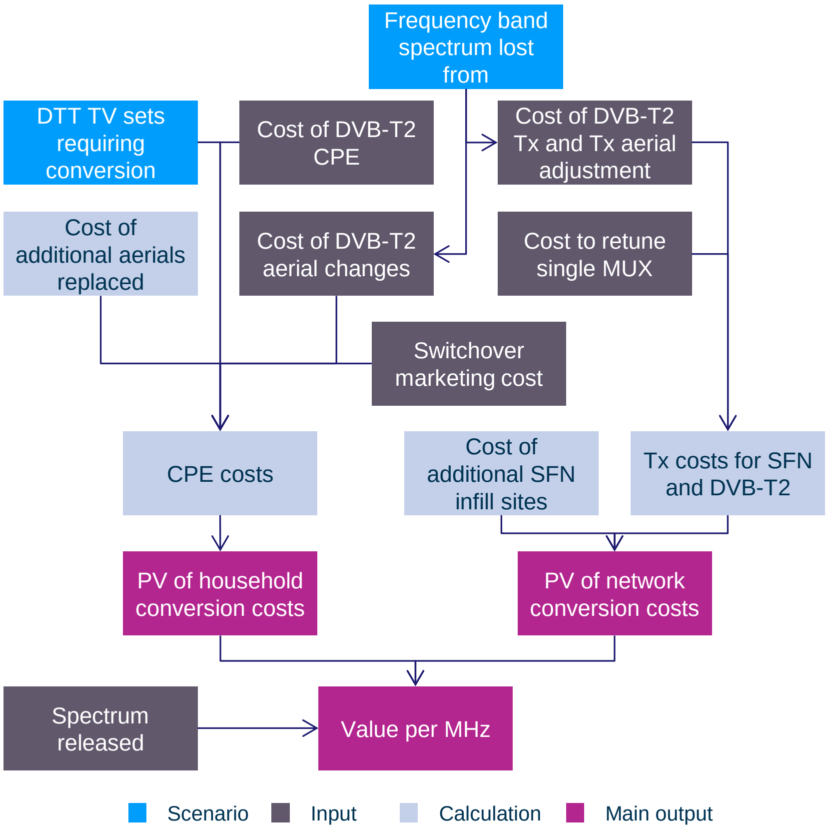


Figure 4.19: Flow diagram of the move of a MUX to SFN (Channel 36) on top of a DVB-T2 upgrade, LCA methodology [Source: Analysys Mason, 2012]

As with DVB-T2, all costs related to household conversion are split using the PSB vs. COM coverage factors and all site and transmitter costs are allocated by costing the actual number of PSB and COM sites requiring modification.

It is our view that the option of converting a COM MUX to using an SFN provides a lower cost alternative for MUX operators collectively and therefore would result in lower opportunity cost associated with the spectrum. As such the costs of implementing the move of the COM MUX to an SFN is split equally between all PSB and COM MUXs.

The total spectrum released is 120MHz (80MHz from the move to DVB-T2 and 40MHz from the move to SFN). Given the SFN is to be moved to Channel 36, 8MHz of new spectrum will also be used in the 600MHz band. As this spectrum is not situated in the DTT bands considered, the full 120MHz is used as the denominator in finding the cost per MHz, which is shown in Figure 4.20 below.

Figure 4.20: LCA cost for move to SFN and DVB-T2 technology upgrade (CPE replacement Scenarios 1-4) [Source: Analysys Mason, 2012]

	Channels 21 to 30 (GBP thousand/ MHz/annum)	*Channels 39 to 48 (GBP thousand/ MHz/annum)*	*Channels 49 to 60 (GBP thousand/ MHz/annum)*
Total	538–1448	522–1416	482–1337
Per PSB	586–1574	568–1539	524–1454
Per COM	490–1322	475–1292	439–1221

The total costs of the DVB-T2 upgrade are identical to the costs shown for the DVB-T2 upgrade response option above, in Section 4.3.2. Incremental costs of transferring to use an SFN are then added before the combined total is divided by the new amount of spectrum released. The same scenarios as for DVB-T2 are modelled, including the level of CPE replacement and the four-year conversion period

The cost results for CPE replacement Scenario4 are slightly lower than for a response which involves only a DVB-T2 upgrade (as the CPE costs are spread over a greater spectrum saving), however the results for CPE replacement Scenario1 are slightly greater due to the increased requirement for aerial replacement arising for the SFN.

A breakdown of the total mitigation cost for CPE replacement Scenario 1 is shown below in Figure 4.21.

Figure 4.21: Net present value breakdown into cost categories for LCA, for the move to SFN and DVB-T2 technology upgrade in CPE replacement Scenario 1 [Source: Analysys Mason, 2012]

NPV categories	*Channels 21 to 30 (GBP thousand)*	*Channels 39 to 48 (GBP thousand)*	*Channels 49 to 60 (GBP thousand)*
Cost of replacement CPE	84 056	84 056	84 056
Costs of domestic aerial changes	678 761	651 793	585 097
Costs of re-engineering TXs	925	925	925
Costs of re-engineering TX aerials	2207	2094	1944
Costs of re-planning	418	418	418
Costs associated with publicity	148 717	148 717	148 717
Loss (/savings) from transmission	-13 304	-13 304	-13 304
Total	**901 780**	**874 699**	**807 853**
Spectrum released	120.0MHz	120.0MHz	120.0MHz
Value/MHz/Annum	**538**	**522**	**482**

DP approach

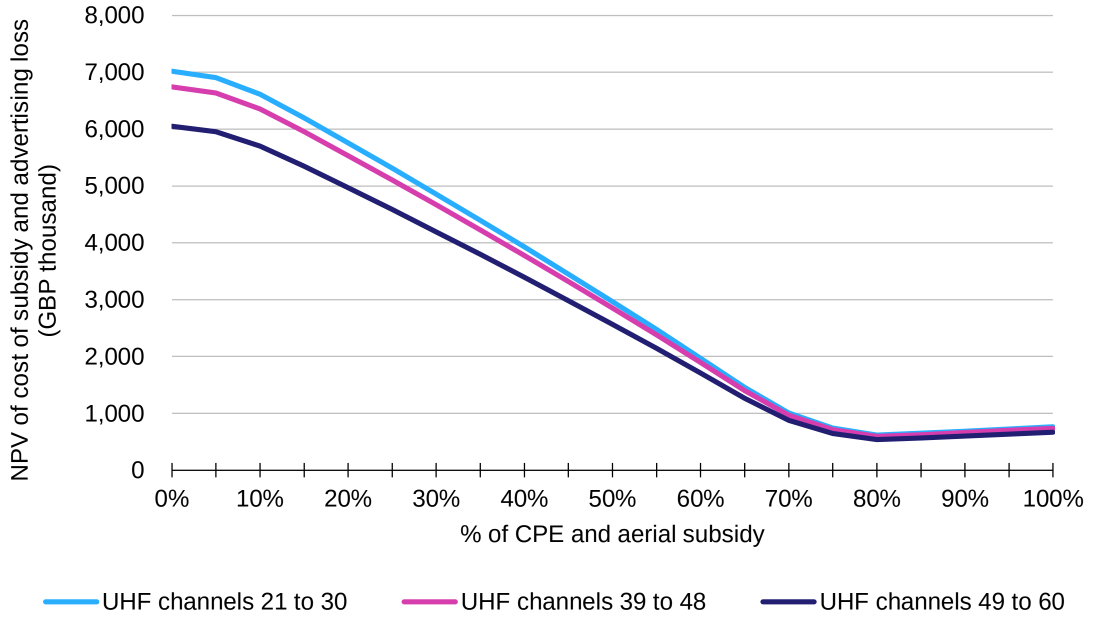
It is assumed that advertising revenues are distributed between TV platforms based only on the number of primary sets (i.e. ignoring secondary and tertiary sets) on each competing platform. As such we assume operators are not affected by the loss of non-primary sets, and so the SFN and DVB-T2 DP approach is incremental to CPE replacement Scenario 1 under the LCA approach, which only considers the cost of replacing primary sets.

For the move to SFN and DVB-T2, an optimal CPE subsidy of around 80% is applied. As with the DVB-T2 upgrade this level is relatively high due to the incremental costs of staying on the platform being relatively high. A lower subsidy would result in households switching away from DTT and a significant loss in advertising revenues, and therefore MUX slot revenues. The exact trade-off between these two costs relative to the subsidy given is shown below in Figure 4.23 for each of the three DTT bands. Figure 4.22 below shows the opportunity costs for each DTT sub-band split between PSB and COM MUXs.

Figure 4.22: DP cost for move to SFN and DVB-T2 technology upgrade (CPE replacement Scenario 1) [Source: Analysys Mason, 2012]

	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
Total	451	438	405
Per PSB	487	472	438
Per COM	415	403	373

Figure 4.23: NPV optimisation for DP method move to SFN and upgrade to DVB-T2 [Source: Analysys Mason, 2012]



A further breakdown of the total mitigation costs for CPE replacement Scenario 1 is shown below in Figure 4.24.

Figure 4.24: Net present value breakdown into cost categories for DP, for a move to SFN and a DVB-T2 technology upgrade [Source: Analysys Mason, 2012]

NPV categories	Channels 21 to 30 (GBP thousand)	Channels 39 to 48 (GBP thousand)	Channels 49 to 60 (GBP thousand)
Cost of replacement CPE	67 221	67 222	67 224
Costs of domestic aerial changes	542 818	521 258	467 936
Costs of re-engineering TXs	925	925	925
Costs of re-engineering TX aerials	2207	2094	1944
Costs of re-planning	418	418	418
Costs associated with publicity	148 717	148 717	148 717
Loss from advertising	6 630	6 366	5 715
Loss (/savings) from transmission	-13 304	-13 304	-13 304
Total	755 632	733 697	679 575
Spectrum released	120.0MHz	120.0MHz	120.0MHz
Value/MHz/Annum	**451**	**438**	**405**

As can be seen, the costs for vacating UHF Channels 21 to 30 are still higher than those seen in other sub-bands, as the DVB-T2 upgrade causes the majority of aerials to move out of group. However all households will now need to access Channel 36 to receive the MUX using SFN and a larger number of aerials in the Channel 49 to 60 also go out of group. A full description of the aerial replacements can be found in Annex A.

4.3.4 Move of up to 7 channels to use the 600MHz band

The currently preferable option for moving frequencies would be to the (near) empty group of channels in the 600MHz band (as this has the greatest chance of leaving aerials in-group). Currently 7 empty channels exist between UHF channels 31-37, with channel 38 used for PMSE. The majority of costs of moving any channels comes from both replacement of out-of-group receiver aerials, and the retuning of transmitter site aerials – as channels overlap it makes sense to move as many channels as possible, i.e. the full 7, to achieve economies of scale and reduce the overall cost per MHz.

We consider the mitigation cost we have calculated of just moving 7 channels to be appropriate to determine the opportunity cost. However, we note as a caveat that as it is not possible to move more than 7 channels to the 600MHz band, this option could not be used in isolation for vacating any of the entire bands considered. The actual practical requirements to vacate a full band are discussed in more detail in Arqiva's recent report on vacating the 700MHz band[59].

59 '700 MHz Clearance Planning Options Based on Existing Usage', Arqiva, March 2012

LCA approach

The cost of moving 7 channels to the 600MHz band is determined by four key drivers under the LCA case:

- the cost of receiver aerial changes resulting from moving channels
- the cost of re-engineering transmitters and re-engineering transmitter aerials
- the costs of frequency re-planning to fully vacate the saved spectrum
- the costs associated with publicity of the channel migration.

Overall the same household and TV usage assumptions from our market model are used as in the DVB-T2 upgrade and SFN+DVB-T2 models. As with these other mitigation responses, the number of households considered for aerial replacement is dependent on the CPE replacement scenario modelled.

The number of aerial replacements also depends on the prior location of the moved channels, where it is assumed that the 7 channels are contiguous and fit neatly within any one of the three DTT sub-bands considered.

Unlike the DVB-T2 or SFN options, the move of several channels does not affect every household, and in many cases will require nothing more than an STB retune and no receiver aerial replacement, even in households which are affected. This means that awareness needs to be raised with only a proportion of DTT platform users and all marketing costs are therefore scaled to the number of households affected.

The overall calculation flow is illustrated in Figure 4.25 below.

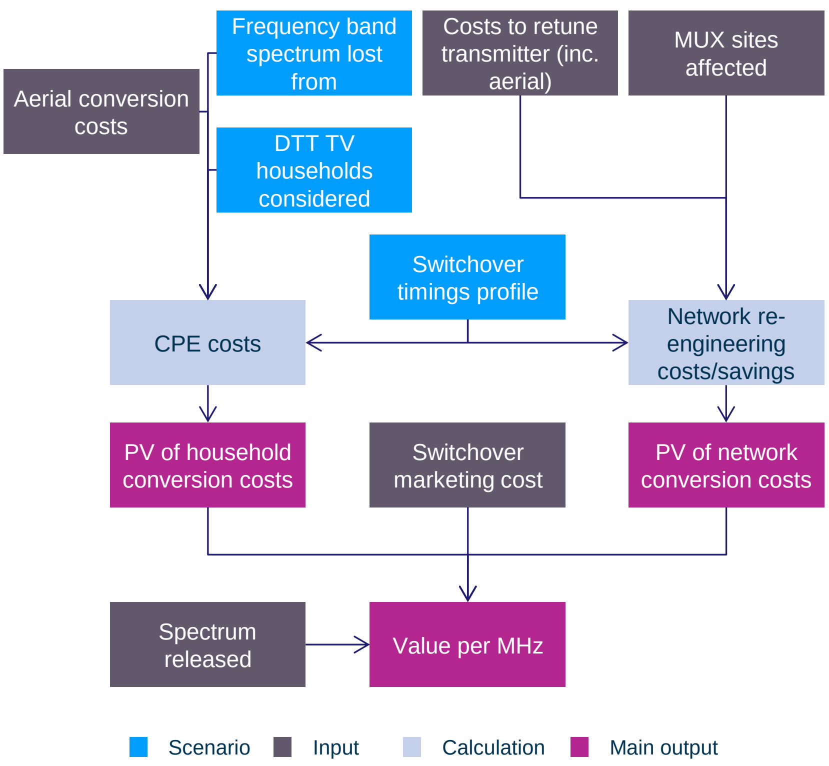


Figure 4.25: Flow diagram of the move of 7 channels to the 600MHz band, LCA methodology [Source: Analysys Mason, 2012]

As with other mitigation responses, all costs related to domestic aerial changes and marketing are split using the PSB versus COM coverage factors and all site and transmitter costs are allocated by costing the actual number of PSB and COM sites requiring modification.

As 7 channels are moved the total spectrum vacated is 56MHz, however we note that unlike in the Freesat or DVB-T2 alternatives this does not relate to an overall spectrum saving but rather a spectrum displacement. As mentioned in Section3.4.1, it is our understanding that the opportunity costs of the new band moved to do not need to be included in the calculation of the cost of moving.

The range of costs for CPE replacement Scenarios 1-4 for each sub-band are shown in Figure 4.26 below.

Figure 4.26: LCA cost for moving 7 channels to the 600MHz band (CPE replacement Scenarios 1-4) [Source: Analysys Mason, 2012]

	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
Total	74–74	321–563	424–765
Per PSB	80–80	347–610	460–830
Per COM	69–69	294–515	388–699

A further breakdown of the total mitigation cost for CPE replacement Scenario 1 is shown below in Figure 4.27.

Figure 4.27: Net present value breakdown into key factors for LCA, for moving 7 channels to the 600MHz band [Source: Analysys Mason, 2012]

NPV categories	Channels 21 to 30 (GBP thousand)	Channels 39 to 48 (GBP thousand)	Channels 49 to 60 (GBP thousand)
Costs of domestic aerial changes	0	196 840	276 753
Costs of re-engineering TX aerials	1120	1111	1018
Costs of re-planning	418	418	418
Costs associated with publicity	56 732	52 518	53 701
Total	**58 271**	**250 887**	**331 892**
Spectrum released	56.0MHz	56.0MHz	56.0MHz
Value/MHz/Annum	**74**	**321**	**424**

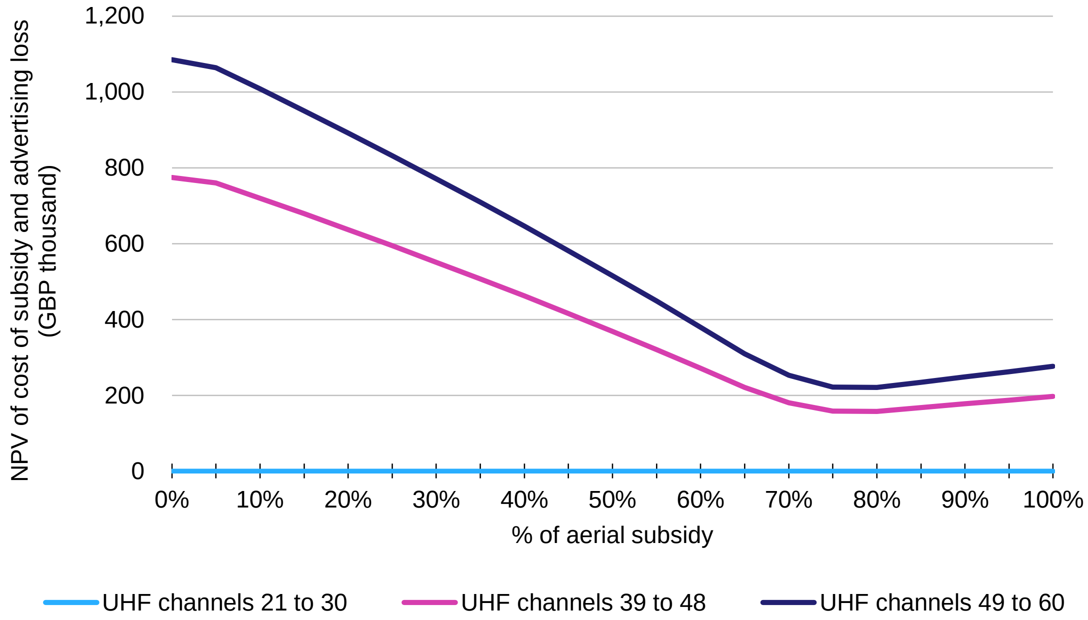
The spectrum loss mitigation response of moving channels to the 600MHz band gives low overall cost ranges; especially in vacating spectrum in Channels 21 to 30 where no receiver aerials require replacement. As can be seen, in this case the majority of cost would be driven by an advertising campaign needed to inform users to rescan for the DTT MUXs which would have to move channels.

DP approach

As discussed previously, it is assumed that the DP approach is always incremental to CPE replacement Scenario 1 under the LCA approach. This is due to advertising revenues being allocated on the basis of primary users, and as such the DP results are only calculated for CPE replacement Scenario1[60].

For the 600MHz migration response, an optimal CPE subsidy of around 80% is calculated (as shown in Figure 4.28 below). Only receiver aerials (and no other CPE) need to be replaced (and in the case of Channels 21 to 30, nothing needs replacing) and therefore fewer users leave the platform than in the case of other mitigation responses.

Figure 4.28: NPV optimisation for DP method upgrade to DVB-T2 [Source: Analysys Mason, 2012]



The costs using the DP approach are shown in Figure 4.29 below.

Figure 4.29: DP cost for moving 7 channels to the 600MHz band (CPE replacement Scenario 1) [Source: Analysys Mason, 2012]

	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
Total	74	270	353
Per PSB	80	293	383
Per COM	69	248	324

60 Scenario 1 relates to replacements only for the primary DTT-only TV CPE/aerial in any household.

A further breakdown of the total mitigation costs for CPE replacement Scenario 1 is shown below in Figure 4.30.

Figure 4.30: Net present value breakdown into cost categories for DP, for moving 7 channels to the 600MHz band [Source: Analysys Mason, 2012]

NPV categories	Channels 21 to 30 (GBP thousand)	Channels 39 to 48 (GBP thousand)	Channels 49 to 60 (GBP thousand)
Costs of domestic aerial changes	0	157 472	221 403
Costs of re-engineering TX aerials	1120	1111	1018
Costs of re-planning	418	418	418
Costs associated with publicity	56 732	52 518	53 701
Loss from advertising	0	0	0
Total	**58 271**	**211 519**	**276 541**
Spectrum released	56.0MHz	56.0MHz	56.0MHz
Value/MHz/Annum	**74**	**270**	**353**

4.4 LCA and DP opportunity costs for secondary interleaved own use of DTT spectrum for local TV

In 2012, a parliamentary instrument was put in place to create a statutory framework for local TV in the UK[61], and a consultation run by Ofcom.[62]Under this framework, new local TV stations have been created.

Local TV content is currently assumed to be broadcast using geographically interleaved DTT spectrum, and so is considered to be a secondary user of the spectrum. (We consider national DTT to be the primary user of the DTT spectrum).

Local TV is expected to become a key user of interleaved DTT spectrum within the next few years. By 2015, the earliest date that AIP may be applied, there will therefore be an opportunity cost to removing local TV MUX operators' access to the interleaved DTT spectrum. In particular if a DTT spectrum band were to be allocated to an alternative use which did not allow for secondary interleaved usage (such as mobile), then the local TV service would no longer be able to operate as it does today.

As local TV and PMSE are classed as secondary users, they are not considered to apply any constraint on alternative uses[63], until such time as the primary user (national DTT) vacates the

61 See http://www.legislation.gov.uk/uksi/2012/292/contents/made

62 See http://stakeholders.ofcom.org.uk/binaries/consultations/localtv/statement/local-tv-statement.pdf

63 PMSE, which is the only other user that could currently operate using the interleaved spectrum for alternative use, is able to use other non-scarce spectrum and so does not need to be considered in this context.

spectrum. As such, we do not believe that a consideration of alternative uses is necessary in calculating opportunity costs for interleaved spectrum used by local TV.

As discussed in section 4.1.2, we do not believe there to be excess demand for interleaved spectrum for local TV use in the DTT bands. However, this conclusion of no scarcity within the TV interleaved spectrum does not prevent there being real costs of providing local TV services by other means if the ability to use some of the interleaved spectrum be removed. The scarcity conclusion does however suggest that despite this non-zero value to current users, the use of interleaved spectrum for local TV is not denying other spectrum users access so there should be no charge levied on this use.

We have identified 3 potential different responses to a loss of spectrum for local TV MUX operators:

- moving to use an alternative channel, either in the 600MHz band or in an alternative spare geographically interleaved channel within the current DTT bands
- providing local TV services via a national MUX slot, though this may require either a significant number of slots or a slight re-engineering of the current delivery method for national DTT
- ceasing local TV operations, though we note that this may not be considered a viable or acceptable option in practice.

In consideration of local TV we assume that the service will be fully functional by 2015, i.e. the earliest date that AIP might be applied to broadcasting.

Ofcom's award of new local TV licences has been broken into two phases. The licences have already been awarded as part of Phase 1. There is some uncertainty as to whether further local TV licences will be awarded in Phase 2[64] (therefore the level of service to be maintained in this case is not clear). We therefore only consider Phase 1 local TV stations, assumed to be available to all households[65] where DTT is available inside each locality.

As per the national DTT own use modelling, we have considered different CPE replacement scenarios under the LCA methodology where the replacement of aerials forms a part of the response:

- CPE Scenario 1: replacements of aerials only where the primary household TV is on the DTT platform
- CPE Scenario 2:replacements of aerials where the primary or secondary household TV is on the DTT platform
- CPE Scenario 3: replacements of aerials where any TV in the household is on the DTT platform.

64 Ofcom intends to introduce local TV areas in a phased approach, with 21 locations chosen for the initial 'Phase 1' and advertised under a single MUX licence. In addition MUX licence applicants were asked to propose other locations (from the list of 23 remaining locations) they would also serve, which would then form a 'Phase 2' roll-out.

65 Using the Ofcom definition of *digital preferred service area* (DPSA) households.

The WACC for the local TV MUX operator is assumed to be equivalent to that of the main DTT MUX operators (i.e. both use Arqiva's WACC of 10.4%). However, we note that in reality the WACC may be slightly higher, given the greater risk of its customer base (2 semi-national, and many small marginally profitable local TV stations) and uncertainty over its business prospects. Additionally it is possible that the local MUX operator could be run as a not for profit organisation, as in the case of the BBC's application[66], in which case the WACC could be lower than shown. A higher WACC could theoretically lead to either a higher or lower opportunity cost depending on the mitigation response followed[67].

As with DTT and DAB a cost per MHz is calculated by dividing the cost of a spectrum-loss mitigation response by the total amount of spectrum vacated under the approach. This however does not take into account the geographical area of the local TV spectrum use. To calculate the opportunity cost per MHz beyond the current areas, a national level reference rate could be found by scaling the amount of spectrum vacated by the percentage of UK population covered at each MHz. We do not carry out this calculation.

In the sub-sections below we discuss each of the different potential responses of the local TV MUX operator to a loss of spectrum, under both the LCA and DP approaches.

Again, these different responses are not necessarily real options which local TV MUX operators might consider, but rather hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum.

4.4.1 Move of local TVMUXs to alternate frequency channels

LCA approach

For each local TV area we consider whether the service could be provided using an alternative channel that would be 'in group' with the current locality's main aerial grouping. This would allow for a move that avoided the need for aerial replacement within the local area in question. We first consider a move to the 600MHz band, and where this is not possible consider interleaved use of other existing DTT channels within the aerial groups' range.

The value of the spectrum to local TV users under this approach is calculated as the sum of incremental transmission costs and aerial conversion costs per MHz of spectrum released. The availability of other DTT channels is based on an analysis of the usage of channels in each geographical area by national MUXs. Where a suitable alternative channel is available, the costs are limited to the change in transmission costs.

While the aerial groups that can accommodate the move of a local TV MUX to the 600MHz band are known, calculating the most appropriate replacement channel for an aerial grouping where the

66 See: http://licensing.ofcom.org.uk/binaries/tv/local-tv/mux-applicants/BBC.pdf

67 The impact depends upon the relative profiles of the changes in revenues and costs over time resulting from the mitigation response.

600MHz band is 'out of group' is significantly more difficult. Such an exercise would require detailed radio planning tools to calculate definite alternatives. Rather than undertake such an extensive exercise, we consider the sensitivity assumptions of 25%, 50% and 75% of sites (those where the 600MHz band is not 'in group') where an appropriate alternative 'in group' existing DTT channel cannot be found. In these cases, aerial conversion costs are calculated as the cost of replacing narrowband out-of-group aerials. In addition we include the publicity costs associated with the marketing and communication of switchover for this subset of consumers.

The approach followed is illustrated in Figure 4.31 below.

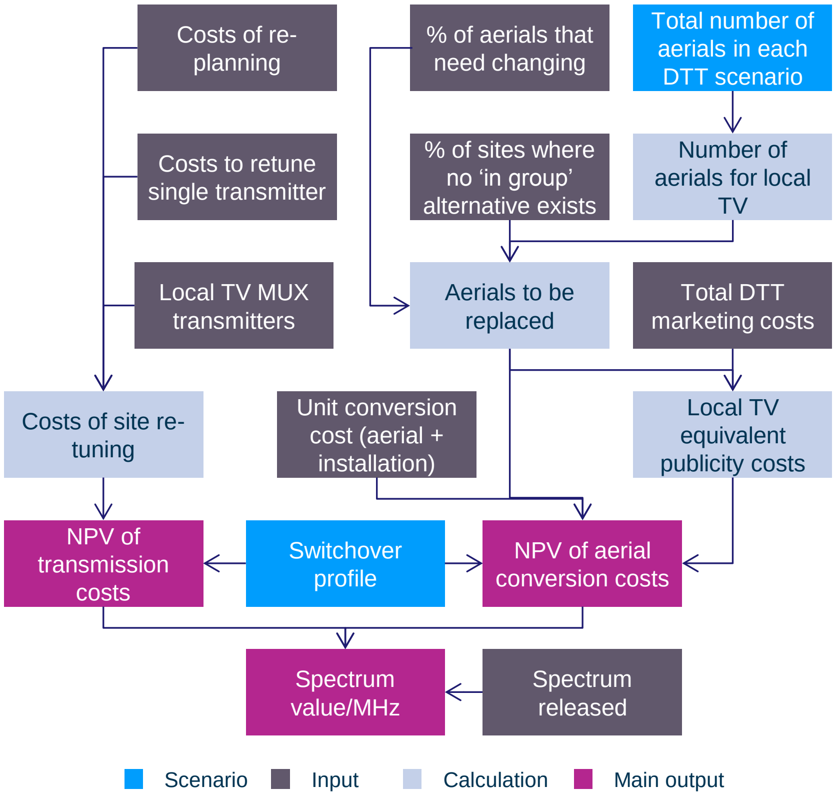


Figure 4.31: Flow diagram of the move of local TV to alternative frequency channels, LCA methodology [Source: Analysys Mason, 2012]

The cost to undertake this spectrum loss mitigation strategy is relatively low and is shown below in Figure 4.32

Figure 4.32: Cost of spectrum loss mitigation strategies, given different levels of sites where no alternative 'in group' channel can be found [Source: Analysys Mason, 2012]

Mitigation strategy	*25% of sites (GBP thousand /MHz/annum)*	*50% of sites (GBP thousand /MHz/annum)*	*75% of sites (GBP thousand /MHz/annum)*
CPE replacement Scenario 1	25.78	**51.23**	76.68
CPE replacement Scenario 2	44.12	87.90	131.69
CPE replacement Scenario 3	50.28	100.22	150.17

As with national DTT, we consider that CPE replacement Scenario 1 is likely to be the most relevant. Additionally, following some preliminary analysis, we believe that the assumption that 50% of sites requiring alternative bands cannot find one ‘in group’ is the most appropriate.

DP approach

The cost of moving the local TVMUXs to different channel sunder the DP approach is calculated as the sum of incremental transmission costs and of losses in revenue, averaged per MHz of spectrum released.

This calculation is identical to the LCA methodology calculation for this response, except that the local MUX operators which are now ‘out-of-group’ would choose not to pay for the replacement of aerials. This is because the cost of providing a replacement aerial is likely to outweigh the revenue that will be generated from local TV from an average household. This assumption is confirmed by our calculations.

As such it is assumed that those people who now no longer have the appropriate aerial to receive the local TV service will effectively leave the platform. While it is possible that some users would self-fund a new aerial, we assume that this would be a small proportion.

As in the national DTT DP cases, this reduction in the number of local TV viewers reduces the advertising revenues of the broadcast stations, and consequently reduces local MUX operator revenues. It is assumed that the local TV stations pay the MUX operator on a cost basis and so their loss of revenues is not passed through to the MUX operator, however as the semi-national stations pay on a fully commercial basis, they may have the opportunity to pass through their advertising losses.

The calculation flow for the DP approach is illustrated in Figure 4.33 below.

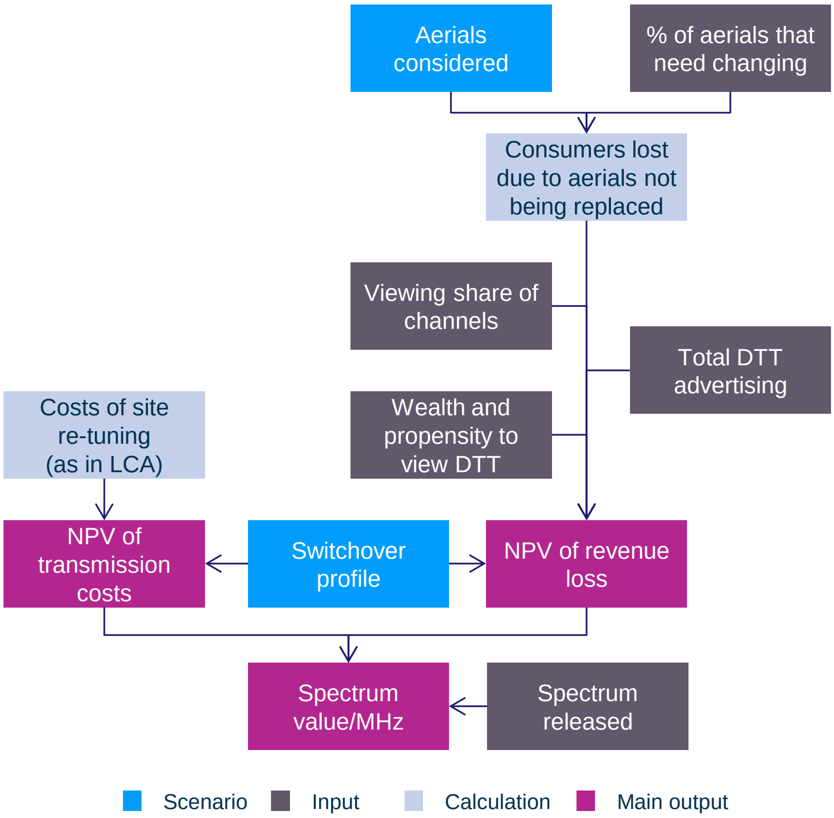


Figure 4.33: Flow diagram of the move of local TV to alternative frequency channel, DP methodology [Source: Analysys Mason, 2012]

The cost to undertake this spectrum loss mitigation strategy is shown below in Figure 4.34. The cost in this case is mostly attributable to loss of advertising to the two semi-national stations; however as the semi-national programmes are assumed only to gain a market share of viewers of 0.19%[68] each, this cost is not large compared to other local TV scenarios.

Figure 4.34: Cost of spectrum loss mitigation strategies, given different levels of sites where no alternative 'in group' channel can be found [Source: Analysys Mason, 2012]

Mitigation strategy	*25% of sites (GBP thousand /MHz/annum)*	*50% of sites (GBP thousand /MHz/annum)*	*75% of sites (GBP thousand /MHz/annum)*
CPE replacement Scenario 1	1.28	2.24	3.19

4.4.2 Switch local TV to a national MUX

One potential spectrum loss mitigation response would be to move each of the local TV stations (including the 2 semi-national stations) to broadcast from a national MUX.

68 Calculated as the average viewing share for non BBC, ITV, C4, C5 and Sky channels, as used in the FTI consulting paper on MuxCo commercial viability.

Under current broadcasting transmission methods, a dedicated MUX slot is required for each unique local TV station in a region, as all the national MUX channels are multiplexed by region before distribution to sites. This method is evidently extremely expensive, and therefore we consider it does not require modelling as a potential LCA.

However, if the national broadcasting network could be adapted to have a local re-multiplexer at each site for insertion of the local TV service, as is used by the local MUX operator to combine semi-national and local TV stations, then far fewer slots would be needed to broadcast all of the local TV stations. Excluding the local stations broadcasting from the Winter Hill transmitter, 3 national DTT MUX slots would provide 2 slots for the semi-national stations (which would effectively become national stations) and 1 slot for local TV, which would be reused for different stations on a local basis.

One difficultly arises from the Winter Hill transmitter, which is intended to broadcast three local TVMUXs using a 'petalling' approach. As the national DTT network does not use petalling on Winter Hill, but rather an omnidirectional antenna, three MUX slots would be required to transmit the three local TV stations. This means that either 5 MUX slots would be needed nationally, or possibly the semi-national slots may accept losing coverage from the Winter Hill transmitter in return for the additional coverage gained from being on the national MUX network, in which case only 3 national MUX slots would be required.

LCA approach

To calculate the costs under this potential mitigation response, we take the current price for a national MUX slot multiplied by the required number of MUX slots, less any local transmission cost savings from turning off the local TV network. This approach is illustrated in Figure 4.35 below.

As with the opportunity cost calculations for national DTT, this cost is averaged per MHz of spectrum released.

We model the local transmission savings for the closure of the local MUX network as the sum of the transmitter operating expenditure, as taken from the Arqiva reference offer prices[69], saved over all local TV sites and the other MUX company operating costs as detailed in Ofcom's viability report[70].

The national MUX slot costs are assumed to amount to leasing the cheapest DTT national MUX slots available. Recent prices for the lowest value slots are taken from the FTI Consulting report and amount to between GBP3-4 million per year, compared to a willingness to pay of potential buyers (not yet on the platform) of GBP1-3 million per year.

69 As published for Local TV on the 1 Jun 2012. See: http://licensing.ofcom.org.uk/binaries/tv/local-tv/Reference_Offer_Guidance.pdf

70 'The commercial viability of MuxCo', FTI consulting on behalf of Ofcom, 26 Oct 2011.

This represents a marked decrease from the prices of GBP10 million purportedly paid by some TV station providers around2005, but given our calculated average MUX slot revenue of GBP6.8 million[71]seems a reasonable price for the lowest value slots.

As the stations would be transmitted across the national network there are no additional CPE or aerial costs incurred. While the number of potential viewers would increase when moved to the national MUX, it is assumed that few additional people are likely to view the station outside of the currently defined areas given its specific local content. The calculation flow for this response is shown in Figure 4.35 below.

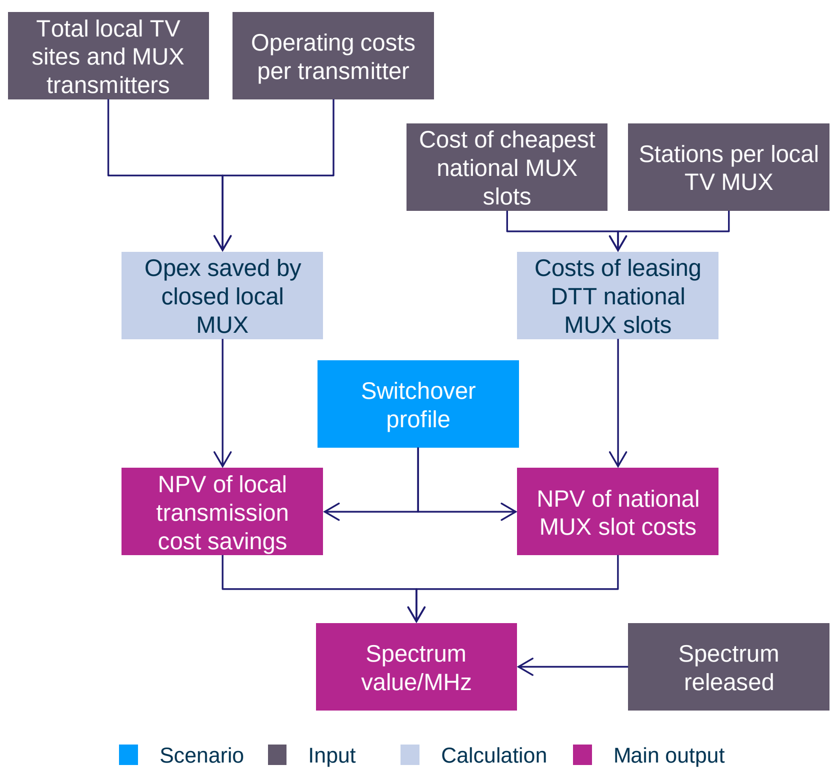


Figure 4.35: Flow diagram of the move of local TV to national MUX slots, LCA methodology [Source: Analysys Mason, 2012]

The costs to undertake this spectrum loss mitigation strategy are shown below in Figure 4.36 below. We have shown both options discussed above, however we believe that the service to be kept constant should be defined as the *number* of people covered by the semi-national MUX, and as such allow the exact location of the people covered to change (i.e. the 'best case').

Mitigation strategy	*Mitigation cost (GBP thousand/MHz/annum)*
Best case (allowed trade off of loss of semi-national operators with gain in other areas)	69.9
Worst case (no loss allowed)	127.1

Figure 4.36: Cost of LCA approach [Source: Analysys Mason, 2012]

71 As taken from the SDN and Digital 3&4 annual accounts.

DP approach

As there are no CPE or aerial costs included in the cost of this response, there is no potential to reduce any subsidy for the DP case. There is however a potential option to not transfer across the semi-national MUX and hence reduce the number of national MUX slots required to 1. This would also require a merger of the Manchester, Liverpool and Preston local TV stations, which all broadcast from Winter Hill, due to reasons discussed above.

The additional costs to be included in the opportunity cost to the MUX operator are therefore the predicted revenues generated by the semi-national stations, and Liverpool and Preston local TV stations. As discussed below, the MUX operator is assumed to provide carriage at commercial rates to the 2 semi-national stations and at-cost to the two local stations.

The costs to undertake this spectrum loss mitigation strategy is shown below in Figure 4.37.

Mitigation strategy	Mitigation cost (GBP thousand/MHz/annum)
DP	27.5

Figure 4.37: Cost of DP approach [Source: Analysys Mason, 2012]

In both the LCA and DP cases, the costs of this response are above those of continuing to provide local TV services using alternative channels.

4.4.3 Close down the local TV service

DP approach

The final spectrum-loss mitigation option under the DP methodology would be to close down the entire local TV service. This response is not applicable under the LCA methodology.

In this case, the cost is calculated as the foregone future revenues of local TV less any local transmission cost savings, averaged per MHz of spectrum released. The local transmission cost savings are modelled in an identical fashion to the LCA method of moving local TV to use national MUX slots, as discussed above.

We assume three stations per local TV MUX in the modelled areas, two of which are semi-national while one is local. In the case of closing the local TV service the MUX operator would lose revenue from all the local and semi-national stations, however the exact levels of revenue to be received from each type of station depends on the contracts entered into by the operator. In lieu of the terms of these contracts having been established, we have used the Ofcom local TV viability report as a starting point for our assumptions. In this document it is assumed that the semi-national operators will be charged on a commercial basis based on the WTP for a national MUX slot, scaled to the appropriate semi-national coverage gained. Whereas the local TV station will be charged either at the cost of supplying the service to them or at the cost of operating plus a small (10%) mark up.

We note that several of the MUX operator applications have discussed reusing profit from the semi-national MUXs to lower local-TV broadcaster costs. If this is done fully, and the MUX operator is run as a not-for-profit organisation, the opportunity cost from lost profit reduces to zero. We assume that this is not the case and that Ofcom will award the licence to a for-profit organisation. However, we assume that this organisation is likely to keep the local TV station revenues at or as near to cost as possible to ensure the local TV services can continue, and as such that profit from semi-national stations can continue. The calculation flow for this approach is shown in Figure 4.38 below.

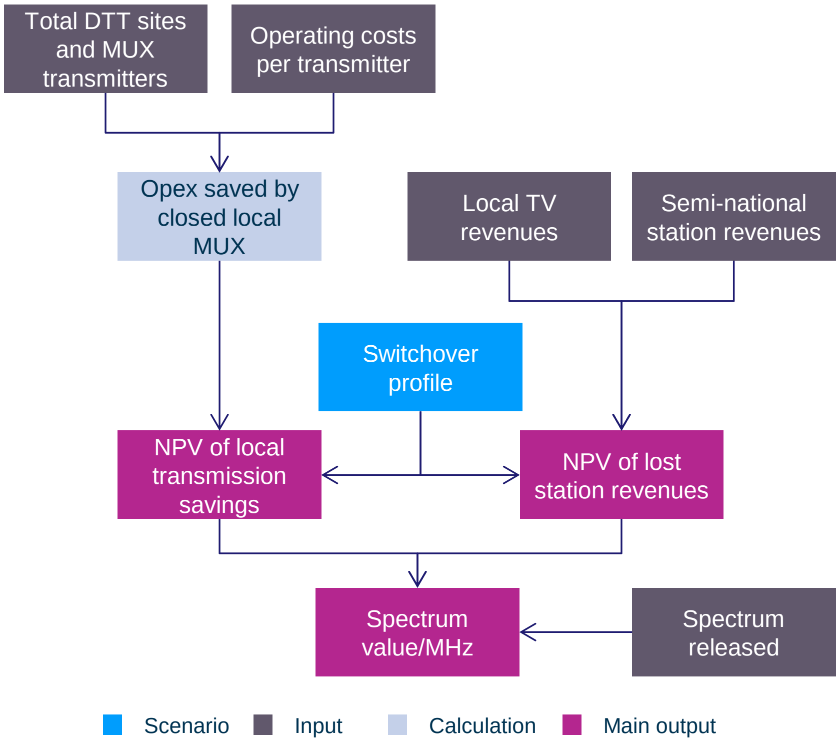


Figure 4.38: Flow diagram for the close of local TV, DP methodology [Source: Analysys Mason, 2012]

The cost to undertake this spectrum loss mitigation strategy is shown below in Figure 4.39. We appreciate that this option may not be a viable alternative in practice given the relevant governmental policy.

That being said, this approach does not provide the lowest cost of the options considered for local TV and therefore does not drive the value of the spectrum to local TV users.

Mitigation strategy	***Mitigation cost (GBP thousand/MHz/annum)***
DP	17.8

Figure 4.39: Cost of closing local TV service [Source: Analysys Mason, 2012]

4.5 LCA opportunity costs for secondary interleaved use of DTT spectrum for PMSE

Like local TV, PMSE makes use of geographically interleaved DTT spectrum, along with many other bands. We have therefore calculated the value in own use of PMSE services in the DTT spectrum bands using the same rationale as was used for the same reasons as we did for local TV.

We have based our PMSE modelling on the 2009 '*Opportunity cost and AIP calculations for spectrum proposed for award to a band manager with obligations to PMSE*' report for Ofcom[43], focussing on the PMSE side of this study rather than the alternative use side.

A summary of this adapted model structure can be seen in Figure 4.40 below.

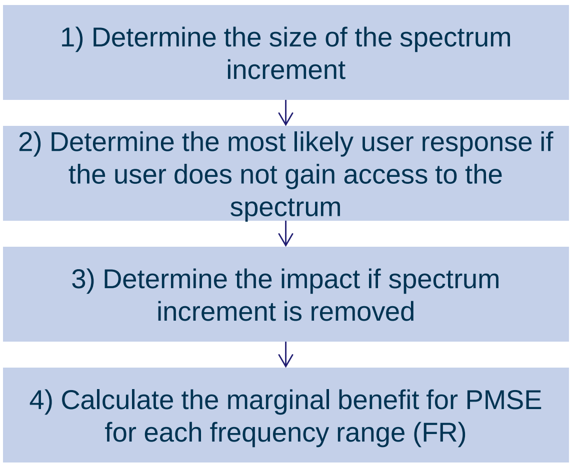


Figure 4.40: PMSE modelling structure [Source: Analysys Mason, 2012]

We have focussed on calculating the LCA for PMSE and have considered responses to the loss of spectrum that had purely cost implications and do not result in a change in output. Specifically, we have focussed on modelling the costs to the PMSE user of moving services to an alternative band. The cost calculation involves a consideration of the stranding of existing equipment and of forcing a PMSE user to reinvest in different equipment at a potentially substantial cost.

Given the value of the output of services generated via the use of PMSE compared to the cost of retuning equipment, it is felt unlikely that PMSE users would reduce their level of output in order to save mitigation costs, and as such the DP case is assumed to be equivalent to the LCA case.

In order to simplify the PMSE spectrum value calculation methodology we have divided both spectrum bands and PMSE applications into several categories.

We have aggregated the bands/sub-bands under consideration in our study into frequency band categories used in the 2009 PMSE spectrum valuation work. The characteristics under consideration include propagation, penetration and future and historical PMSE usage. The categorisation is shown in Figure 4.41 below.

Band/sub-band	Frequency category
470–550MHz	Television interleaved (UHF Channels 21 to 30)
614–694MHz	Television interleaved (UHF Channels 39 to 49)
694–790MHz	Television interleaved (UHF Channels 49 to 60)

Figure 4.41: Band aggregation [Source: Analysys Mason, 2012]

A wide range of PMSE applications make use of geographically interleaved DTT spectrum; however we have followed the approach of the previous PMSE spectrum valuation by grouping them into seven broad categories

- radio microphones
- in-ear-monitors (IEM)
- talkback
- telemetry
- audio links
- video links
- wireless cameras.

While these categories are not exhaustive and there are a few applications not included in our analysis, we feel that the number of applications that do not easily fit into these categories is sufficiently small that their exclusion will not result in a significant impact on our results.

We determined whether these PMSE uses were applicable to the aggregated bands under consideration using data from the Joint Frequency Management Group (JFMG) assignment database. JFMG is currently responsible for the licensing of PMSE use of spectrum on Ofcom's behalf. It maintains a database of each assignment, including details on the category of use, dates and locations. We have received an update of this assignment database for the year ending June 2012 for the purpose of this valuation. According to the JFMG database, the TV interleaved category provided spectrum for all 6 of the application categories used by JFMG as shown in Figure 4.42.

Figure 4.42: 2012 Actual numbers of assignments [Source: JFMG assignment database, 2012]

Band/sub-band	Data	Personal monitor	Audio programme links	Video programme links	Radio microphone	Talkback
470–550MHz	51	2043	28	1	2566	1367
614–694MHz	4	4185	236	0	20 269	828
694–790MHz	0	2301	191	1	9526	4201

As discussed in the 2009 PMSE spectrum valuation report, stakeholder interviews indicate that there is a significant amount of unlicensed use, particularly amongst radio microphone users, which is not taken into account as the database only records purchased assignments. In order to include this unlicensed use in our calculations, we have used Sagentia estimates to derive the amount of radio microphone equipment in the market associated with unlicensed use.

We have used the amount of equipment in the market and equipment replacement parameters such as unit costs and lifetimes by application category as inputs to our modelling. These have been updated from the 2009 PMSE report. In instances where these data were obtained from the stakeholder interviews carried out in the previous valuation, we have trended the data forward using inflation based assumptions where appropriate.

A WACC of 8.4% is used in this calculation of the marginal benefit of PMSE use. This figure is taken from an industry benchmark of WACC for European broadcasting companies and differs from the 10.4% WACC used in the calculations for DTT own use.

The data on assignments and assignment days provided by the JFMG has been used to give both the usage and equipment levels in each frequency range used in our model.

As discussed in Section 4.1.2, we do not believe there to be excess demand for interleaved spectrum for PMSE use in these bands. However, this conclusion of no scarcity within the TV interleaved spectrum does not prevent equipment stranding should the ability to use some of the interleaved spectrum be removed. The scarcity conclusion does however suggest that despite this non-zero opportunity cost, the use of interleaved spectrum for PMSE is not denying other spectrum users access so there should be no charge levied on this use.

We have modelled two possible increment sizes, an entire band and an 8MHz channel. These both differ from the increment size focussed on in the 2009 PMSE report of 200kHz. These spectrum increments were chosen to be consistent with the DTT modelling and the interleaved nature of the spectrum considered. Our modelling and the results for the two increment sizes are discussed in turn below.

4.5.1 Move all items in band

For the calculation of the marginal benefit of spectrum for PMSE users, we assume that as a result of a loss of a spectrum increment, PMSE users would need to relocate to other less congested PMSE bands. Such a course of action would involve purchasing new equipment to replace that stranded in the original band. We use the JFMG database and our estimates of unlicensed usage to derive the amount of PMSE equipment that would be stranded in each spectrum increment. In our modelling approach we have defined spectrum increment sizes as the bands/sub-bands under consideration in this study; that is 470–550MHz, 614–694MHz and 694–790MHz. This is calculated as the proportion of the assignments for the designated PMSE usage category within the relevant band multiplied by the amount of equipment in the market.

The 2009 PMSE report concluded that there was no opportunity cost for this spectrum, or that in the neighbouring Channel 69 as we did not “expect that PMSE equipment would become stranded if a spectrum increment was removed”. In this case we are now considering a much larger spectrum increment than the 200kHz discussed in the 2009 report and the PMSE equipment will not be capable of retuning over this larger range. As such, equipment will be stranded if access to this spectrum is denied to the PMSE users and there will be a cost.

We calculate the annualised marginal benefit separately for each PMSE usage category as the product of the depreciated annualised equipment value[72] and estimates of the amount of equipment in each band. This gives us the cost that would be incurred if each PMSE usage category was required to switch band. In order to determine the value of each spectrum band to PMSE, we must add the marginal benefits for each usage category. The results of this valuation calculation are shown in Figure 4.43 below.

Band/sub-band	Marginal benefit of sub-band (GBP thousand/annum)	Marginal benefit per MHz (GBP thousand/MHz/annum)
470–550MHz	724.2	9.1
614–694MHz	725.6	9.1
694–790MHz	875.8	9.1

Figure 4.43: Value of TV interleaved spectrum to PMSE [Source: Analysys Mason, 2012]

These results are of particular interest when considering the 700MHz band for which there is greater potential that an alternative spectrum user such as mobile will have demand for the entire band.

4.5.2 Move all items in single channel

To move from the marginal benefit valuation results in Section 4.5.1 for the vacation of an entire sub-band to those for the vacation of a single channel within the relevant band, we scale using a multiband factor of 80%. This multiband factor denotes that 80% of PMSE equipment has the capability to work in multiple bands.

A smaller proportion of the equipment is stranded with the loss of a single channel as equipment is much more likely to have a tuning range sufficient that it can work in a nearby channel when the spectrum increment lost is reduced.

It is only the 20% of equipment that cannot be moved that is stranded and as such the marginal benefit per MHz results shown in Figure 4.44 are one fifth of those for the loss of the entire band

Band/sub-band	Marginal benefit of channel (GBP thousand/annum)	Marginal benefit per MHz (GBP thousand/MHz/annum)
470–550MHz	14.5	1.8
614–694MHz	14.5	1.8
694–790MHz	14.6	1.8

Figure 4.44: Value of a single channel to PMSE [Source: Analysys Mason, 2012]

Depending on the mitigation approach used for the primary user of the DTT spectrum, either one of these two PMSE opportunity costs results may be the more appropriate:

72 These values are depreciated using the total asset value multiplied by the proportion of the asset lifetime remaining and annualised to perpetuity using an annualisation factor of 18.37% calculated as 1+(1+inflation)/(1+WACC)

- If the primary spectrum is moved out of the whole band, as is the case in the DTT upgrade to DVB-T2, then the PMSE opportunity cost to move all items in a band should be considered.
- If the primary spectrum users only vacate part of the band (leaving some interleaved spectrum available within the band for PMSE to move to) – as is the case when DTT channels are move to the 600MHz band – then the PMSE opportunity cost to move from a single channel should be considered.

4.6 Summary of opportunity costs for DTT spectrum in own use

Overall, spectrum scarcity was found in the primary DTT spectrum bands, however not in interleaved spectrum.

The total opportunity costs of the spectrum depend on both the opportunity cost in own use, discussed below, and the alternative use opportunity costs, discussed in Section 5.

4.6.1 Primary own use

The costs calculated under both LCA and DP approaches are summarised in Figure 4.45 below. The costs are calculated under CPE replacement Scenario 1 (the replacement of only primary DTT sets) in all cases, as this is felt to be the most likely to occur in practice, and is closest to the replacement criteria for TV DSO[73].

[73] Though we note this was only available for people aged 75 or over, who have lived in a care home, get DLA, or Mobility supplement, or are registered blind or partially sighted.

Figure 4.45: Costs for DTT across each spectrum mitigation option under LCA and DP cases (in CPE replacement Scenario 1) [Source: Analysys Mason, 2012]

Mitigation strategy	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
LCA: Switch of DTT platform to Freesat	1238	1238	1238
DP: Switch of DTT platform to Freesat	718	718	718
LCA: Upgrade of MUXs to DVB-T2	532	394	**413**
DP: Upgrade of MUXs to DVB-T2	454	342	357
LCA: Upgrade of MUXs to SFN and DVB-T2	538	522	482
DP: Upgrade of MUXs to SFN and DVB-T2	451	438	405
LCA: Move of 7 channels to use the 600MHz band	**74**	**321**	424
DP: Move of 7 channels to use the 600MHz band	**74**	**270**	**353**

Note: Values in red represent the lowest-cost response for each sub-band

Under both the LCA and DP approaches, the lowest-cost mitigation strategy for a spectrum loss in either Channels 21 to 30 or Channels 39 to 48 is the move of 7 channels to the 600MHz band. The lowest-cost mitigation strategy for Channels 49 to 60 in the LCA case is the upgrade of the DTT broadcasting technology to DVB-T2. However, under the DP approach the move of 7 channels to the 600MHz band remains the lowest-cost response.

Switching to the Freesat platform is the most costly mitigation response because it involves the provision of new CPE but also a loss of future profits on the DTT platform. Options involving a DVB-T2 upgrade also require the replacement of CPE, whilst moving channels to the 600MHz band requires only some receiver aerials to be replaced. In general therefore this is the lowest cost of the mitigation responses considered.

Channels 49 to 60 are the range often referred to as the 700MHz band. This band has the highest cost in own use of any of the DTT spectrum. However, as shown in Section5, there is also a substantial opportunity cost in alternative (mobile) use for this spectrum band which does not exist for the other DTT spectrum bands.

Based on the results above, the total annualised opportunity cost in own use for DTT primary spectrum is around GBP71.2 million under LCA and GBP61.4 million under DP[74]. This gives us an indicative average opportunity cost of GBP11.9–10.2 million per national DTT multiplex *before* consideration of alternative uses. The calculation of an average ‘per-MUX’ opportunity cost

74 The ‘Channels 21 to 30’ consists of 10MHz channels totalling 80MHz. The other two groupings total 80MHz and 96MHz. These bandwidths are multiplied by the minimum LCA and DP opportunity costs, highlighted in red in the table, to result in total opportunity costs in own use of GBP71.2 million per annum under LCA and GBP61.4 million per annum under DP.

assumes that every MUX uses each grouping of channels equally. We also note that the actual opportunity cost for each individual MUX may differ from the average, which is simply obtained by dividing the total value by 6 (the number of MUXs). For example, PSB and COM MUXs may have different opportunity costs for the spectrum due to different coverage obligations.

4.6.2 Interleaved own use

The costs of different responses by local TV providers to a loss of spectrum calculated under both LCA and DP are summarised in Figure 4.46 below. For consistency with the national DTT calculations above, the costs are calculated under CPE replacement Scenario 1 in all cases, but as with national DTT the exact level of equipment to be replaced would need to be decided at the time of any spectrum loss.

Mitigation strategy	*LCA case (GBP thousand/MHz/annum)*	*DP case (GBP thousand/MHz/annum)*
Move to alternate frequency channel	**51.2**	**2.24**
Switch local TV to a national MUX	69.9	27.5
Close local TV	N/A	17.8

Figure 4.46: Costs for local TV spectrum loss mitigation under LCA and DP cases in CPE replacement scenario 1 [Source: Analysys Mason, 2012]

Note: Values in red represent the lowest cost response for each approach

These results suggest a value for the spectrum in secondary interleaved use for local TV purposes of GBP51 200 per MHz per annum under the LCA approach and GBP2240 per MHz per annum under the DP approach.

The difference between the LCA and DP values for moving to another frequency reflects the fact that in the DP case there is no assumption that replacement receiving aerials will be provided to households that do not offer high value to the platform.

A calculation of the opportunity cost for the complete DTT spectrum band may need to reflect the opportunity cost of the primary users and the opportunity cost of secondary interleaved users. Where spectrum is not considered scarce the values calculated for current users would represent the opportunity costs were the spectrum to be considered scarce.

As such it may be necessary to distribute the total local TV opportunity costs calculated above across the relevant spectrum sub-bands. We do this by calculating the total opportunity cost for each band using the proportional household coverage (i.e. the number of households covered by MUXs in each sub-band). We then convert this into a comparable ‘per MHz’ value to the own and alternative use values by dividing this sub-band allocated opportunity cost by the total width of the sub-band in MHz. These sub-band allocated costs are shown in Figure 4.47 below.

Figure 4.47: Costs for local TV spectrum loss mitigation spread across all DTT spectrum, under LCA and DP cases in CPE replacement Scenario 1 [Source: Analysys Mason, 2012]

Mitigation strategy	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
LCA: Move to alternate frequency channel	**28.3**	**0.3**	**27.4**
DP: Move to alternate frequency channel	**1.2**	**0.0**	**1.2**
LCA: Switch local TV to a national MUX	38.6	0.4	37.3
DP: Switch local TV to a national MUX	15.2	0.1	14.7
DP: Close local TV	9.9	0.1	9.5

Note: Values in red represent the lowest-cost response for each sub-band

The lowest-cost mitigation strategy for a spectrum loss in either Channels 21–30, 39–48 or 49–60 is the move to alternative frequency channels for both LCA and DP cases. These values represent the opportunity costs by sub-band are highlighted in red in the table above.

The opportunity costs of the smaller geographical area interleaved DTT spectrum, as used by PMSE services, are summarised in Figure 4.48 below.

Figure 4.48: Opportunity costs for PMSE spectrum mitigation spread across all DTT spectrum, under LCA and DP [Source: Analysys Mason, 2012]

Mitigation strategy	Channels 21 to 30 (GBP thousand/ MHz/annum)	Channels 39 to 48 (GBP thousand/ MHz/annum)	Channels 49 to 60 (GBP thousand/ MHz/annum)
LCA+DP: Moving entire sub-band	9.1	9.1	9.1
LCA+DP: Moving one channel	**1.8**	**1.8**	**1.8**

Note: Values in red represent the lowest-cost response for each sub-band

The lowest opportunity cost mitigation strategy for a spectrum loss (of one channel) in Channels 21–30, 39–48 or 49–60 is the move to an alternative frequency under both the LCA and DP approaches. This opportunity cost is very low at only around GBP1800 per MHz per annum.

5 Opportunity cost in alternative use for DTT spectrum

This section discusses the opportunity cost calculations for the DTT spectrum in alternative-use. The remainder of the section is set out as shown in Figure 5.1 below.

Figure 5.1: Map of Section 5 [Source: Analysys Mason, 2012]

Following the completion of TV DSO in the UK, the spectrum used for DTT will occupy the frequencies 470–550MHz and 614–790MHz. However, the 614–790MHz DTT block is likely to have very different alternative uses in different parts. Therefore we have split the block into two sub-bands for the purpose of our alternative use analysis. The frequency blocks considered could potentially be used for a range of alternative services rather than the current DTT usage. These are shown in Figure 5.2 below and also described earlier in Section3.1.

Figure 5.2: Summary of potential alternative uses for DTT spectrum bands [Source: Analysys Mason, 2012]

Band/Sub-band	Possible alternative uses
470–550MHz (currently DTT)	**PMSE, local TV,** white-space devices, PBR, public safety (also used for fixed links in parts of ITU Region 2)
614–694MHz (currently DTT)	**PMSE, local TV,** white-space devices, PBR, public safety
694–790 MHz (currently DTT)	**Mobile broadband, local TV, PMSE,** PBR, white-space devices, public safety

Within this study we have modelled the LCA of the alternative uses[75] likely to have the highest valuations, specifically those highlighted in bold in Figure 5.2. These highest value alternatives are discussed in more detail below

Local TV services have been discussed under own use in Section 4.4. We have not considered in detail public safety or white space device uses as we consider these are unlikely to provide a higher alternative use value than DTT use of this spectrum.

Mobile broadband services

One of the key alternative uses for the higher-frequency DTT spectrum in the 700MHz band is mobile services, and specifically LTE-based services (largely consisting of mobile broadband). The case for use of the 700MHz spectrum band for mobile broadband is so prevalent that the recent WRC-12 conference in Geneva called for the band to be allocated as co-primary for DTT and IMT.[76] Ofcom's recent statement on the future strategy for UHF Bands IV and V has indicated that the 600MHz band may play a role in mitigating the 700MHz loss.

Notwithstanding any practical difficulties of re-allocation of the 700MHz band, in this section we provide calculations of the opportunity cost of the 700MHz spectrum for mobile use. Other factors such as whether a re-allocation is appropriate or how it should be carried out are beyond the scope of this study.

Due to the economies of scale gained through the use of internationally harmonised bands for mobile services, it is highly likely that the 700MHz band will offer significant value to mobile users. Conversely, international harmonisation of bands and the resulting economies of scale in handset manufacturing mean that bands which are not internationally harmonised are unlikely to be of significant value to mobile operators, as discussed in Section 4.1.1.

Therefore we only model mobile services in the harmonised 700MHz band where we believe they are likely to provide a high opportunity cost worthy of detailed consideration.

75 As specified by Ofcom, there is no DP modelling of the alternative uses due to the reasons stated in Footnote 7 of the Executive Summary.

76 The provision decision at WRC-12 allows for a co-primary mobile allocation in the 700MHz band within ITU Region 1 to be approved for mobile broadband at WRC-15, subject to relevant technical work.

Should the expected levels of international harmonisation of the 700MHz band fail to materialise, we would expect this to have an impact on the value of the band to mobile operators in the UK. In particular, the opportunity costs we calculate would represent an overestimate. However, we do not consider this failure to harmonise to be a likely scenario.

PMSE services

Another key alternative use for all DTT spectrum bands considered is PMSE. Unlike the issues seen with mobile regarding a need for internationally harmonised spectrum, most PMSE users are adept at using any available spectrum bands, and adapting their equipment accordingly. PMSE can also operate effectively within spectrum that is shared with other primary services, as evidenced by the use of DTT interleaved spectrum in the UHF band, as well as its sharing with defence applications in various bands in the UK.

In addition, PMSE, while not the most profitable spectrum user considered, is a major contributor to the social and cultural wellbeing of the UK, being used by thousands of organisations to aid broadcasting delivery, entertainment and major events such as the Olympic and Commonwealth Games. Any such value is not captured by the opportunity cost calculations in this study, but may need to form part of Ofcom's considerations for future policy decisions relating to PMSE or indeed other spectrum uses including DTT.

An important consideration is that the substitution of DTT with any service – such as mobile – which blocks out the entire frequency has the secondary effect of reducing the available DTT interleaved spectrum for PMSE usage. We have already discussed the value of PMSE in 'own use' on the interleaved DTT spectrum in Section 4.5, and in this section, we consider whether there is any value attached to PMSE in alternative use (i.e. the opportunity cost of PMSE having exclusive use of spectrum in any of the DTT bands).

5.1 Opportunity cost of mobile use

5.1.1 Overall approach to modelling the opportunity cost of mobile use

We have modelled the opportunity cost of mobile as an alternative use in the 700MHz spectrum band (614–694MHz) as we feel it is likely this will be the highest value alternative use, with potential of having a higher value than that for own use DTT. This potential for a high valuation is due to the opportunity which internationally harmonised equipment presents for launching mobile data services in this spectrum band.

In general, there may be many sources of value of additional spectrum to a mobile operator. In the context of an LCA calculation we believe that it would only be appropriate to include the network cost savings related to the *technical* value of the additional spectrum. As a result, our model of the opportunity cost of the 700MHz band for mobile communications as an alternative use considers only the network cost savings achievable by a mobile operator through having access to additional spectrum in the 700MHz band.

There are likely to be other sources of commercial value to mobile operators but calculating the full value of spectrum to a mobile operator would correspond to a DP approach.

5.1.2 Approach to modelling network cost savings

We base our model around the spectrum requirements of a generic operator. Our calculations of network cost savings are based on an assessment of the number of sites which the modelled generic operator could avoid building if more spectrum (in the 700MHz band) were to be made available to it. We model over a 20-year period from the start of 2015 but include a terminal value in our assessment of the present value of costs faced by the generic operator.

In the remainder of Section 5.1.2 we provide a more detailed description of our generic operator, our approach to calculating network cost savings and an overview of the key inputs and technical considerations driving our model. In Section 5.1.3 we present the opportunity costs calculated by our modelling and in Section 5.1.4 we briefly compare these to some international benchmarks of mobile spectrum value, as a sanity check of our modelling outputs.

Generic operator approach

We have modelled the network costs to a generic operator of expanding their network to cover forecasted demand increases for mobile services with access to different amounts of spectrum from the 700MHz band[77].

As the UK mobile market currently has four competing networks, we have assumed 25% market share of subscribers for our modelled generic operator, across both handsets and mobile broadband devices, as can be seen in Figure 5.3 below.

Subscribers	2015	2020	2025	2030	2034
Market: Handsets (millions)	42.8	54.1	67.7	70.7	72.8
Market: MBB devices (millions)	8.2	11.6	16.7	17.7	18.2
Generic operator: Handsets (millions)	10.7	13.5	16.7	17.7	18.2
Generic operator: MBB devices (millions)	2.1	2.9	4.2	4.4	4.5

Figure 5.3: Market size and share forecasts [Source: Analysys Mason, 2012]

Our generic operator's spectrum holdings before the release of the 700MHz spectrum band equates to roughly one quarter of the total available mobile spectrum (prior to the possible availability of spectrum in the 700MHz band). This reflects Ofcom's goal to maintain four credible national

77 We note that each of the four UK mobile operators have different characteristics to our generic operator and therefore may have different values for the 700MHz spectrum.

wholesale operators. The specifics of the generic operator spectrum holdings is shown in Figure 5.4 below

Spectrum band	Total spectrum allocated from the band	Generic operator spectrum holding
800MHz	2×30MHz	2×10MHz
900MHz	2×35MHz	2×5MHz
1800MHz	2×70MHz	2×15MHz
2.1GHz	2×60MHz	2×15MHz
2.3GHz TDD	40MHz	10MHz
2.6GHz	2×70MHz	2×15MHz
2.6GHz TDD	50MHz[78]	10MHz

Figure 5.4: Generic operator spectrum holdings[Source: Analysys Mason, 2012]

Having access to additional spectrum reduces the number of additional mobile sites that need to be built by a mobile operator in order to provide both capacity and coverage. This reduction in required site numbers reduces both the opex and capex of the mobile operator.

As can be seen in Figure 5.4, our generic operator is assumed to have spectrum holdings across all bands allocated for mobile services and an existing network of sites prior to the release of the 700MHz spectrum band. Under this scenario, national coverage for LTE will already be well established by the time of the release of the 700MHz band and 700MHz spectrum will not entail any significant savings on the number of sites needed for coverage. Therefore our model focuses on capacity considerations.

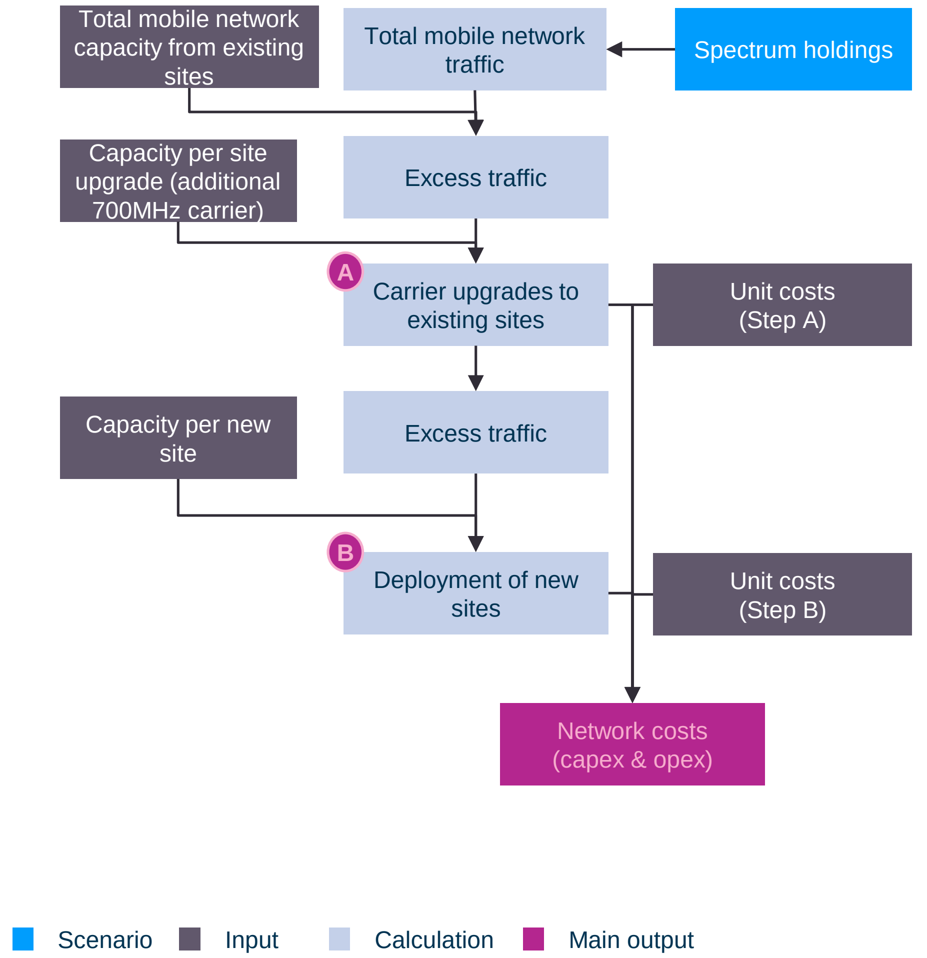
Approach to the capacity site calculation

Having access to 700MHz spectrum means that the generic operator can add additional carriers to existing sites so as to increase capacity. This can be done at relatively low cost and is illustrated by Step A in Figure 5.5 below. If this capacity increase is insufficient then additional new sites may also be needed. The cost of these, step B in Figure 5.5, is much greater. In the event that no 700MHz spectrum is available to the generic operator, no low-cost 700MHz carriers can be added and a greater number of high-cost new sites will need to be built, relative to a case with 700MHz spectrum.

Our model calculates the total mobile network traffic and the distribution of traffic per site and compares this to a calculation of the total capacity per site, as illustrated in Figure 5.5. This approach enables a calculation of exactly how many new sites are needed given the generic operator’s existing spectrum portfolio and how many could be avoided given access to different amounts of 700MHz spectrum. By taking into account the costs of each capacity upgrade option, we calculate the network costs year on year in the case with and without 700MHz spectrum and take the NPV of these network costs in each case. The difference in these NPVs represents the technical value of the 700MHz spectrum to the mobile operator.

78 May be reduced to an effective amount of around 40MHz based on distribution between operators

Figure 5.5: Illustration of the opportunity cost of mobile model structure [Source: Analysys Mason, 2012]



To calculate the network infra-structure requirement we take into account:

- the total number of sites in operation
- the total busy hour traffic on the network
- the distribution of that traffic between geotypes and across the sites within each geotype
- the capacity per site with and without 700MHz spectrum
- the capacity boost offered by additional 700MHz carriers.

The algorithm we apply to calculate the network infra-structure requirements can therefore be summarised as follows:

- We calculate how many sites are unable to carry the required amount of traffic using existing capacity.
- For any such sites, if any 700MHz spectrum is available, we calculate whether adding the available 700MHz carrier will provide sufficient capacity.
- For any of these sites where this is not the case, we model a site split (i.e. a new site is built and traffic shared equally between the overloaded site and the new site).

- We repeat this calculation each year and the relevant unit costs for sites and carriers are applied so as to calculate the incremental network costs.

Distribution of traffic and sites

The comparison of traffic and capacity allows for the calculation of the number of new sites and new carriers required, each of which has a cost, and is therefore key to our calculation.

In order to calculate the costs to the generic operator of providing sufficient capacity for all traffic it is therefore important to know exactly how the traffic and capacity (sites) are distributed.

In order to achieve this we model across several different geotypes, as used by Ofcom in the calls to mobile model (CTM) for assessing the costs of mobile termination[79]. Both the site and traffic split by geotype for our generic operator are equal to that of the average operator in the Ofcom CTM. As can be seen in Figure 5.6 below, traffic per site is significantly higher in urban geotypes.

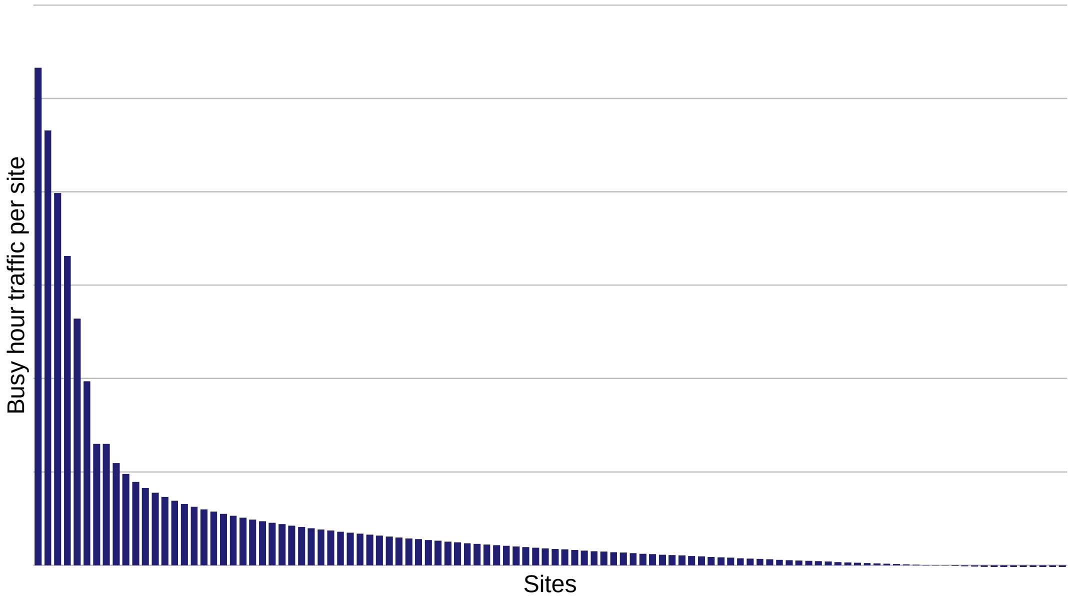
Geotypes	Proportion of generic operator sites	Proportion of generic operator traffic
Urban	7%	13.20%
Suburban 1	35%	60.82%
Suburban 2	12%	14.43%
Rural 1	13%	6.08%
Rural 2	13%	1.75%
Rural 3	4%	0.41%
Rural 4	5%	0.21%
Highways	11%	3.09%

Figure 5.6: Traffic and site split across geotypes [Source: Analysys Mason, 2012]

In addition to the split of traffic between geotypes, there will be an uneven distribution of traffic across sites within any given geotype. We have used a traffic distribution derived from traffic patterns observed from mobile operators we have worked with of the form $y = a \times \ln(x) + b$. An illustration of this relationship can be seen in Figure 5.7 below

79 See http://www.ofcom.org.uk/static/wmvct-model/model-2011.html

Figure 5.7: Illustration of traffic distribution within geotypes [Source: Analysys Mason, 2012]



Importance of low-frequency spectrum

Sub-1GHz spectrum is often regarded as being of particular importance to mobile operators because of its superior propagation characteristics. The advantage of low-frequency spectrum is mainly attributed to its ability to reduce the costs to an operator with regards to coverage. These propagation characteristics are illustrated in Figure 5.8 below, which is not to scale.

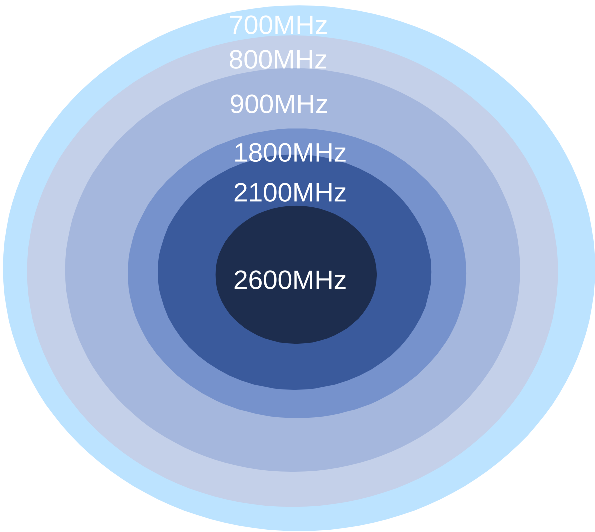


Figure 5.8: Illustration of the propagation characteristics of different frequency bands [Source: Analysys Mason, 2012]

While the generic operator's existing spectrum holdings will allow it to provide adequate coverage, there are still substantial advantages of sub-1GHz spectrum in the provision of capacity as around 50% of the coverage area of each cell is outside the reach of supra-1GHz spectrum. The value of sub-1GHz spectrum is greater than that of higher-frequency spectrum even when capacity is the main concern and more accurately reflects the considerations of mobile operators.

We make the assumption that 30% of network traffic is generated outside the reach of supra-1GHz spectrum, and can therefore be carried only over lower frequencies (i.e. the 700MHz, 800MHz or 900MHz bands), or by building new sites. This split between 'low-frequency-specific' and 'non-low-frequency-specific' traffic has an impact on our model structure and we consider these two traffic groupings separately.

We first calculate the number of additional carriers and sites required to provide adequate capacity for the traffic that can only be served by low-frequency spectrum (or new sites). Any remaining capacity of the sites deployed to service the low-frequency specific traffic is used to carry the remainder of the traffic. We then run additional calculations to see if any additional sites are required in order to carry this remaining 'non-low-frequency-specific' traffic.

Network cost elements

Having access to additional spectrum reduces the number of additional mobile sites that need to be built by a mobile operator in order to provide additional capacity. This reduction in site builds reduces both the opex and capex of the mobile operator.

In this model we are specifically assessing the costs savings with respect to both opex and capex across the following costs elements:

Cost element	*2012 capex (GBP)*	*2012 opex (GBP)*
New site build (including civil works)	112 750	11 275
Carriers for 1 frequency band on a tri-sectored macro site	6000	600
HSPA base station	3500	350
LTE base station	4200	420
Backhaul[80]	15 000	4500
Total for new site[81]	**141 450**	**17 145**
Total for additional 700MHz carrier	**6000**	**600**

Figure 5.9: Opex and capex on cost elements in 2012 [Source: Analysys Mason, 2012]

The unit capex and opex values are taken from averages of values we have seen from working with various mobile operators. In general annual unit opex is around 10% of unit capex although for backhaul we use more detailed assumptions to derive a higher opex figure. The unit costs are

80 We assume that any sites which are upgraded to include 700MHz carriers already have relatively high numbers of other carriers and have therefore previously converted to using leased lines for backhaul. We do not therefore assume any incremental costs for backhaul when a 700MHz carrier is added to a site.

81 This assumes that only carriers for 1 frequency band are added. A site loaded with all available frequency bands, with 700MHz available in 2012, would incur capex of GBP183 450 and opex of GBP21 345.

generally similar to those used by Ofcom in the CTM modelling and replacing the unit costs with those previously used by Ofcom makes little difference to the results.

Key inputs

We have a number of key inputs to our model which are set out below. Given the uncertainty over some of the key input parameters we have followed a sensitivity based approach, considering a base case and a range of values produced by allowing deviations to certain input parameter values used in that base case.

► *Traffic*

We consider the data usage of mobile handsets and mobile broadband devices. We use data from Ofcom's 2011 mobile LRIC model[79] and Analysys Mason Research to derive historical usage and have used exponential growth curves to model the usage forecasts for our base case. We use the Ofcom 2011 mobile LRIC model usage figures as input data for some of our sensitivities.

In our base case, we assume that active offloading[82] increases from 5% to 25% over the modelled period. Details of these inputs are shown in Figure 5.10 below. We have run sensitivities using both higher and lower values for the active offloading percentages.

	2015	2020	2025	2030	2034
Handset traffic per subscriber (GB/sub/month)	1.6	3.0	4.3	5.3	6.0
MBB device traffic per subscriber (GB/sub/month)	12.3	20.5	25.5	28.5	30.0
% active offloading	6%	14%	23%	25%	25%

Figure 5.10: Generic operator traffic forecasts [Source: Analysys Mason, 2012]

Using these traffic inputs alongside those for subscriber numbers gives the following annual total traffic forecasts for the generic operator, laid out in Figure 5.11 below.

	2015	2020	2025	2030	2034
Total generic operator traffic (PB/year)	257	622	1131	1402	1558
Total generic operator traffic net of offloading (PB/year)	253	563	918	1108	1203

Figure 5.11: Generic operator annual traffic forecasts [Source: Analysys Mason, 2012]

82 Our traffic forecasts already take account of inactive offloading such as when a smartphone user connects to their WiFi router when at home. This parameter relates to mobile network operators actively seeking to offload traffic from their mobile networks by setting up, or buying third party access to WiFi hotspots, likely in urban locations, and directing devices on their network to automatically connect using WiFi where available.

We use parameters from the Ofcom 2011 mobile LRIC model[79] to derive our base case portion of traffic that will fall in the busy hour. The relevant parameters are:

- busy days per year: 250
- proportion of traffic in busy days: 80%
- proportion of busy day traffic in the busy hour: 7.5%.

► *Device availability*

We have assumed that 700MHz capable devices will enter the market in the same year as the 700MHz spectrum becomes available to mobile operators, in our base case this is in 2020. We have run sensitivities in which this year of spectrum availability and device entry was brought forward to 2018, which we consider to be the earliest possible year for 700MHz availability for mobile use, and 2026, as used in the 'Techniques for increasing the capacity of wireless broadband networks: UK, 2012-2030' real wireless report for Ofcom.[83]

Our device take up has been extrapolated from Analysys Mason Research figures on historical take up of smartphones and forecast to grow exponentially.

► *Spectrum holdings*

We have assumed that the 700MHz spectrum band includes 2×40MHz of spectrum that would be appropriate for mobile usage. We assume in our base case that this 700MHz spectrum first becomes available in 2020, although we test alternative availability dates as part of our sensitivity analysis. Of this available spectrum we have considered four scenarios in which our generic operator wins a varying amount of spectrum in the 700MHz band:

- Scenario 1: 0MHz
- Scenario 2: 2×5MHz
- Scenario 3: 2×10MHz
- Scenario 4: 2×15MHz.

We are calculating a per-MHz opportunity cost of the spectrum, so the amount of 700MHz spectrum held is only significant to the extent that the per MHz technical value changes. However, we find that this per MHz value can vary quite significantly because for each incremental 2×5MHz lot of spectrum that is added to the generic operator's portfolio, the number of new-build sites avoided decreases. In other words, 2×10MHz of spectrum reduces the number of new site builds required by less than twice the reduction brought about by 2×5MHz of new spectrum. This means that 2×10MHz is not worth as much as double 2×5MHz of spectrum from a network cost saving perspective and is therefore worth less on a per MHz basis.

83 See http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

► *WACC*

We set our base case pre-tax WACC to 6.2% pre-tax real (8.86% pre-tax nominal), in line with the WACC for mobile operators used by Ofcom in its modelling of mobile termination rates.[79] We ran sensitivities using 10.4%, the pre-tax nominal WACC for DTT operators as used in our DTT own use modelling, and a value of WACC between those for mobile and DTT operators (9.63%).

► *Site numbers*

We model an initial number of sites ranging between the highest and lowest per-operator numbers reported for the various operators in Ofcom's technical modelling in support of their combined award final decision (800MHz and 2.6GHz).[84] Our base case uses a value a little higher than the average number of sites reported, 17 500. Recent site sharing agreements suggest that this slightly higher number of sites is appropriate for our generic operator.

► *Technology roadmap and spectral efficiency*

In order to calculate the capacity of each sector, and hence each site, we require information on the technologies used by the generic operator in each spectrum band. A summary of our assumptions over time can be seen in Figure 5.12 below

Bands	2015	2020	2025	2030	2034
700MHz	-	LTE	LTE	LTE	LTE
800MHz	LTE	LTE	LTE	LTE	LTE
900MHz	HSPA	HSPA	LTE	LTE	LTE
1800MHz	GSM	GSM	LTE	LTE	LTE
2.1GHz	HSPA	HSPA	HSPA	HSPA	HSPA
2.3GHz TDD	TD-LTE	TD-LTE	TD-LTE	TD-LTE	TD-LTE
2.6GHz	LTE	LTE	LTE	LTE	LTE
2.6GHz TDD	TD-LTE	TD-LTE	TD-LTE	TD-LTE	TD-LTE

Figure 5.12: Technologies used by the generic operator [Source: Analysys Mason, 2012]

For the two TDD bands in which TD-LTE is used, it is assumed that two thirds of the capacity is to be used for downlink. We have made the following specific assumptions:

- By the start date of the model in 2015 we assume that the generic operator uses HSPA Release 8, dual cell (DC)[85] but that by 2016 it will switch to using HSPA Release 9 with DC and multiple in, multiple out (MIMO).
- We assume that the operator can use LTE Advanced 4×4 MIMO by 2017 but only 2×2 MIMO until that point.

[84] See http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/Annexes1-6.pdf

[85] Dual cell HSPA is sometimes referred to as dual carrier HSPA and allows for the aggregation of 2 carriers using a total of 2x10MHz of spectrum to achieve higher peak data rates and greater spectral efficiency.

- The generic operator is assumed to continue using HSPA in the 900MHz band until 2022 – this is also the year in which GSM switch-off in the 1800MHz band is assumed to take place.

These different releases of the HSPA and LTE technologies have different spectral efficiencies as shown in Figure 5.13 below.

Technology	*Spectral efficiency (bits/second/Hz)*
HSPA Release 8, DC	1.24
HSPA Release 9, DC, MIMO	1.50
LTE Advanced 2×2 MIMO	1.69
LTE Advanced 4×4 MIMO	2.40

Figure 5.13: Spectral efficiency [Source: Analysys Mason, 2012]

All sites are assumed to be tri-sectored macro sites and this allows the calculation of the capacity per site in Mbit/s (in the busy hour).

We also take into account the availability of 700MHz capable devices and do not allow the proportion of traffic carried by 700MHz spectrum to exceed the proportion of devices in the market which are 700MHz capable.

The development of heterogeneous networks (HetNet)[86] enables further offloading; this in our base case was assumed to be 25% throughout the period. We ran sensitivities using both higher and lower values for the impact on offloading of HetNet development.

5.1.3 Results of the modelling

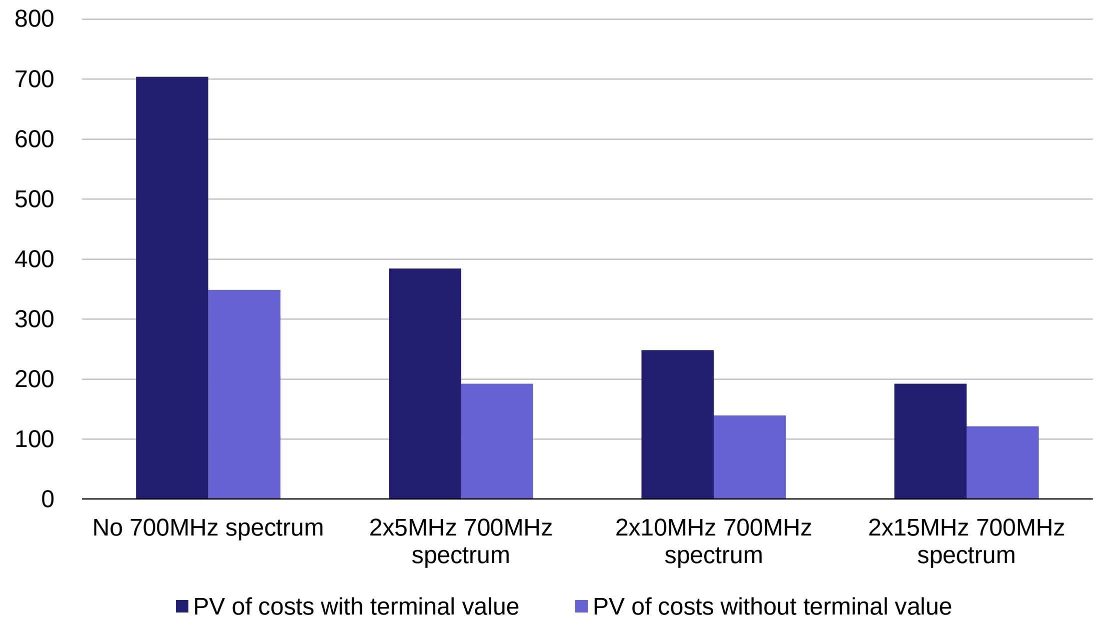
Base case results

The costs of new sites and carriers in each of the 20 modelled years (2015-2034) are calculated and from this we calculate the present value (PV) of network costs in each spectrum holding scenario using the WACC as a discount factor. We also included a terminal value in our PV; this is based on the sum to perpetuity of future network costs, with costs in each future year assumed equal to those in 2034.

In Figure 5.14 below the NPV (in 2015 real terms) of the four different 700MHz spectrum scenarios in the base case can be seen, with the costs to the generic operator decreasing as their allocation of 700MHz spectrum increases.

86 A heterogeneous network uses a diverse set of base-station types in order to both eliminate coverage holes and improve capacity. The integrated addition of low-power nodes to the macro network provides gains through cooperation within the coverage area.

Figure 5.14: NPV of different spectrum holding scenarios in the base case [Source: Analysys Mason, 2012]



The value of incremental amounts of 700MHz spectrum to the generic operator can be found by calculating the difference in the PV of the network costs between scenarios where the generic operator holds different amounts of 700MHz spectrum. For example, the technical value of 2×10MHz of 700MHz spectrum is given by the PV of network costs where the operator holds no 700MHz spectrum minus the PV of network costs where it holds 2×10MHz of 700MHz spectrum.

We have extracted an annualised value of each spectrum increment using an annualisation factor of 1+(1+inflation)/(WACC-inflation). This value per MHz per annum can be defined as the annual amount which would need to be paid in perpetuity such that the present value of the cost was equal to that of a lump sum payment of the full value on day one. This annual payment is set so as to remain flat in real terms, i.e. to increase with inflation in each year.

We understand Ofcom intends to use such an approach in order to set annual licence fees for mobile spectrum. This is the same approach which we have followed for calculating opportunity costs in all uses for the spectrum considered in this study.

Both the full value and the annualised value of the spectrum to the generic mobile operator are shown in Figure 5.15 below.

Figure 5.15: Value of 700MHz spectrum [Source: Analysys Mason, 2012]

	2×5MHz	2×10MHz	2×15MHz
Full value (GBP million)	378	539	606
Annualised value (GBP million/MHz)	2.21	1.58	1.18

Depending on the band plan selected it is likely that either 2×30MHz or 2×40MHz in the 700MHz band could be made available for mobile use. In our base case we assume that 2×40MHz of 700MHZ spectrum is available and therefore that 2×10MHz per (generic) operator is most relevant to consider. Thus we consider a value of GBP1.58 million/MHz/annum to be the appropriate value of the 700MHz spectrum to the generic operator in our base case.

Sensitivities

We ran various sensitivities in order to test the impact of changes in various model inputs on the spectrum valuation. The most realistic and significant of these are considered in more detail below.

► *Date of 700MHz release*

While our base case uses 2020 as the launch year for the 700MHz spectrum band to mobile, we have also considered the impact of launch in both 2018 and 2026. The value of the spectrum with the earliest feasible launch date of 2018 is illustrated in Figure 5.16

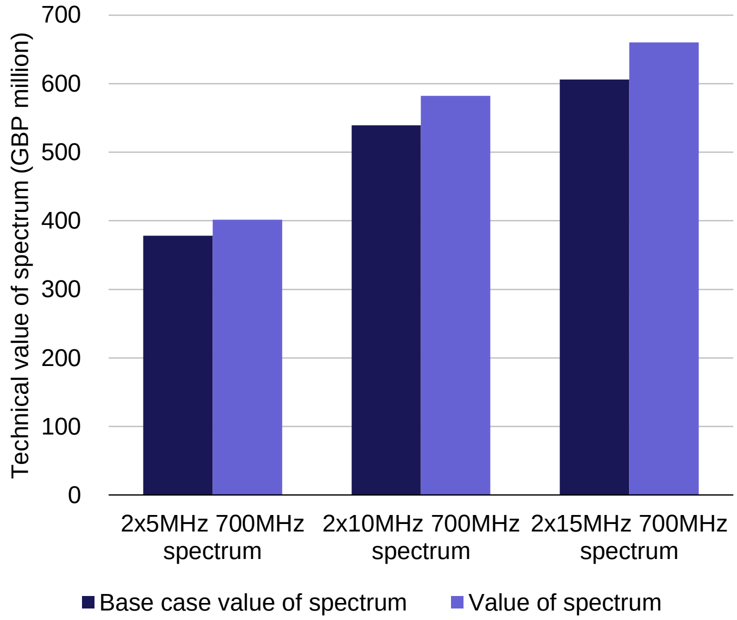


Figure 5.16: Technical value of spectrum to the generic operator with 2018 700MHz spectrum launch [Source: Analysys Mason, 2012]

We considered 2026 based on 'Techniques for increasing the capacity of wireless broadband networks: UK, 2012-2030' real wireless report for Ofcom[83]and the value of spectrum with this late release date in shown in Figure 5.17

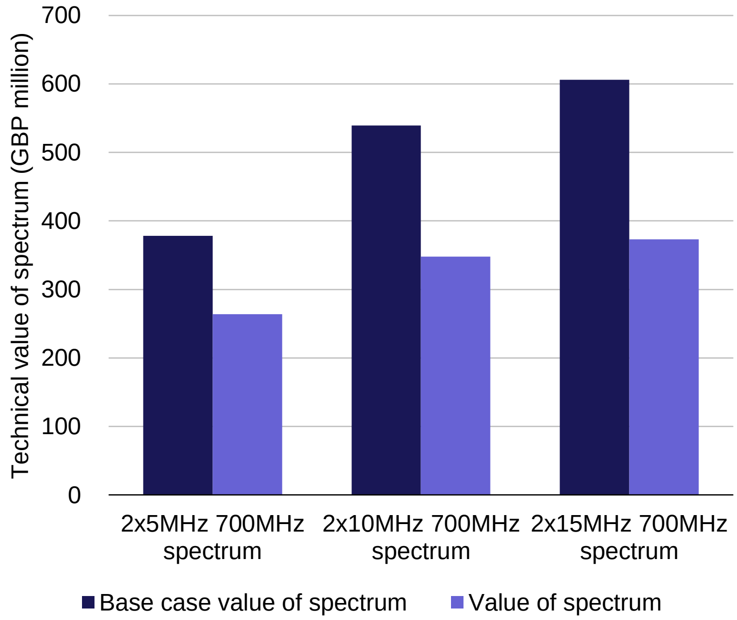


Figure 5.17: Technical value of spectrum to the generic operator with 2026 700MHz spectrum launch [Source: Analysys Mason, 2012]

The impact of delaying the release of 700MHz spectrum to mobile operators is to reduce the value of the spectrum to them as can be seen in the annualised value under the different launch dates in Figure 5.18. This is because many additional sites would already need to be built in advance of 2026 in the absence of any 700MHz spectrum.

Figure 5.18: Annualised 700MHz spectrum value with different launch dates [Source: Analysys Mason, 2012]

Launch plan	***Annualised value per MHz for 2×5MHz (GBP million)***	***Annualised value per MHz for 2×10MHz (GBP million)***	***Annualised value per MHz for 2×15MHz (GBP million)***
700MHz launch in 2018	2.35	**1.70**	1.29
700MHz launch in 2020	2.21	**1.58**	1.18
700MHz launch in 2026	1.54	**1.02**	0.73

► *WACC*

We used an 8.86% nominal WACC in our base case, in line with the real WACC for mobile operators used by Ofcom in its modelling of mobile termination rates.[79] However, we have also considered a higher nominal WACC of 10.4% to correspond with the WACC for DTT operators as used in our DTT own use modelling alongside one between these two values of 9.63%. The results of the technical value calculations with a 10.4% pre-tax nominal WACC are illustrated in Figure 5.19.

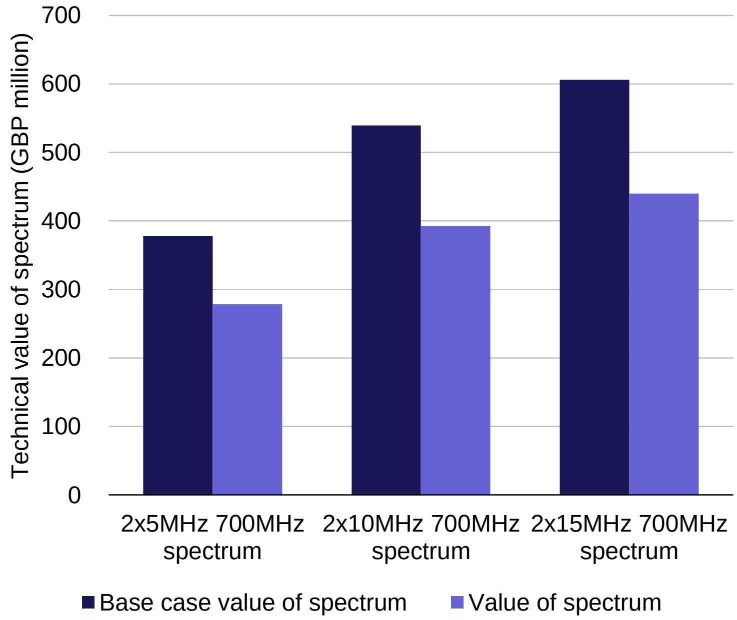


Figure 5.19: Technical value of spectrum to the generic operator with 10.4% nominal WACC [Source: Analysys Mason, 2012]

The annualised spectrum value with the various WACC assumptions shown in Figure 5.20 illustrates that a higher WACC has the impact of reducing the value of the spectrum to mobile operators.

Figure 5.20: Annualised 700MHz spectrum value with different nominal WACC [Source: Analysys Mason, 2012]

WACC	***Annualised value per MHz for 2×5MHz (GBP million)***	***Annualised value per MHz for 2×10MHz (GBP million)***	***Annualised value per MHz for 2×15MHz (GBP million)***
8.86% nominal	2.21	**1.58**	1.18
9.63% nominal	1.89	**1.34**	1.00
10.4% nominal	1.63	**1.15**	0.86

► *Initial site numbers*

We modelled initial site numbers taken from Ofcom's technical modelling in support of their combined award final decision (800MHz and 2.6GHz). The highest site numbers in the Ofcom modelling were 18 500 and the technical value for a generic operator starting with this high number of sites can be seen in Figure 5.21.

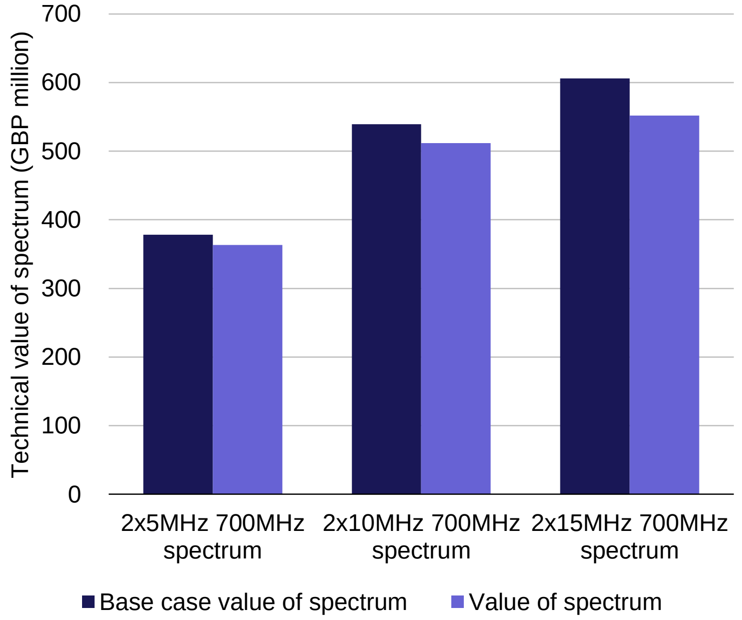


Figure 5.21: Technical value of spectrum to the generic operator with 18 500 starting sites [Source: Analysys Mason, 2012]

Ofcom's technical modelling used 16 000 as the minimum number of operator sites; the impact of this low number of initial sites is illustrated in Figure 5.22

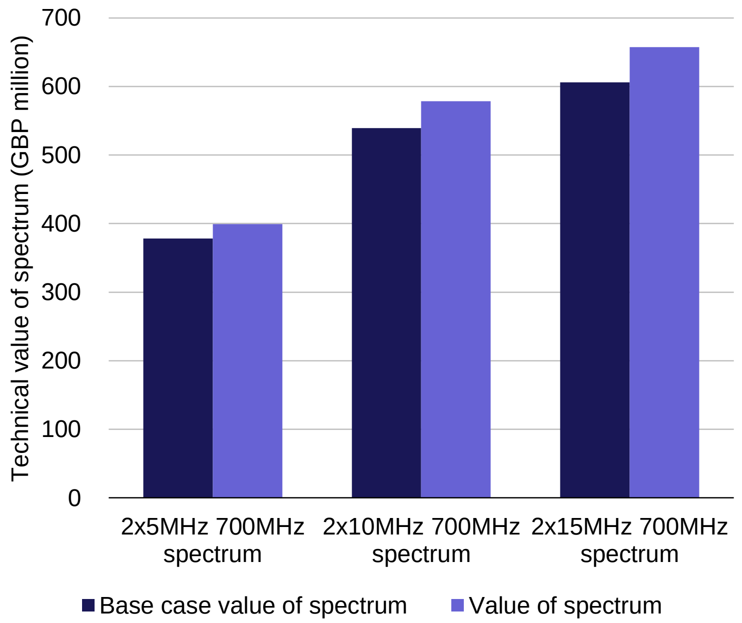


Figure 5.22: Technical value of spectrum to the generic operator with 16 000 starting sites [Source: Analysys Mason, 2012]

A reduction in the initial site number increases the need for additional sites or carriers at the beginning of the modelling period, increasing the value to the operator of the 700MHz spectrum as shown in Figure 5.23

Figure 5.23: Annualised 700MHz spectrum value with different initial site numbers [Source: Analysys Mason, 2012]

Number of sites	Annualised value per MHz for 2×5MHz (GBP million)	Annualised value per MHz for 2×10MHz (GBP million)	Annualised value per MHz for 2×15MHz (GBP million)
18 500	2.12	**1.50**	1.07
17 500	2.21	**1.58**	1.18
16 000	2.33	**1.69**	1.28

► *Spectrum assignments*

There are certain spectrum bands other than the 700MHz band that are yet to be auctioned to mobile, specifically the 800MHz and 2.6GHz bands. We cannot be certain what the eventual assignment of these bands between operators will be. In any case, different operators may have different opportunity costs relative to our generic operator based on existing spectrum holdings. We have therefore considered the impact on the opportunity cost calculation of different assignments of low frequency and 2.6GHz spectrum to our generic operator, as shown in Figure 5.24 below.

Band	Base case	Switched 800/900MHz allocation	High 2.6GHz allocation	Greater low-frequency allocation
800MHz	2×10MHz	2×5MHz	2×10MHz	2×10MHz
900MHz	2×5MHz	2×10MHz	2×5MHz	2×10MHz
2.6GHz	2×15MHz	2×15MHz	2×20MHz	2×15MHz

Figure 5.24: Alternative spectrum assignments considered [Source: Analysys Mason, 2012]

Of these alternative frequency assignments, it is that of a greater low-frequency spectrum assignment that is perhaps most interesting. The technical value to the generic operator of 700MHz spectrum with existing holdings of 2×10MHz of both 800MHz and 900MHz spectrum is illustrated in Figure 5.25 below.

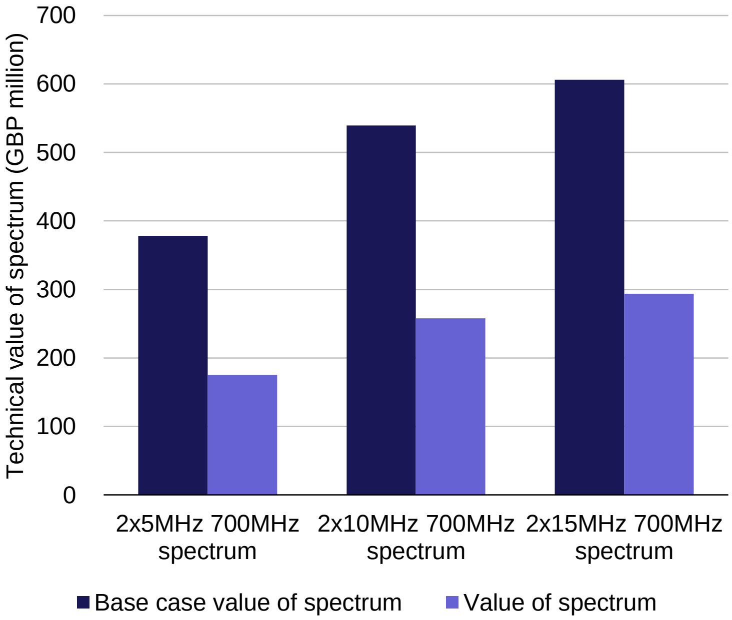


Figure 5.25: Technical value of spectrum to the generic operator with a greater low-frequency spectrum allocation [Source: Analysys Mason, 2012]

As can be seen in Figure 5.26, the greater low-frequency spectrum assignment option significantly reduces the value of 700MHz spectrum to mobile operators; however it is the only alternative spectrum assignment option that makes a significant difference in the valuation.

Figure 5.26: Annualised 700MHz spectrum value with different spectrum allocations [Source: Analysys Mason, 2012]

	Annualised value per MHz for 2×5MHz (GBP million)	***Annualised value per MHz for 2×10MHz (GBP million)***	***Annualised value per MHz for 2×15MHz (GBP million)***
Base case	2.21	**1.58**	1.18
Switched 800/900MHz allocation	2.20	**1.55**	1.16
Greater 2.6GHz allocation	2.22	**1.57**	1.17
Greater low-frequency allocation	1.02	**0.75**	0.57

► *Technology*

We ran sensitivities on the active offloading, HetNet development and spectral efficiency variables and the results of these are displayed in Figure 5.27.

Figure 5.27: Annualised 700MHz spectrum value for scenarios with different technology variables [Source: Analysys Mason, 2012]

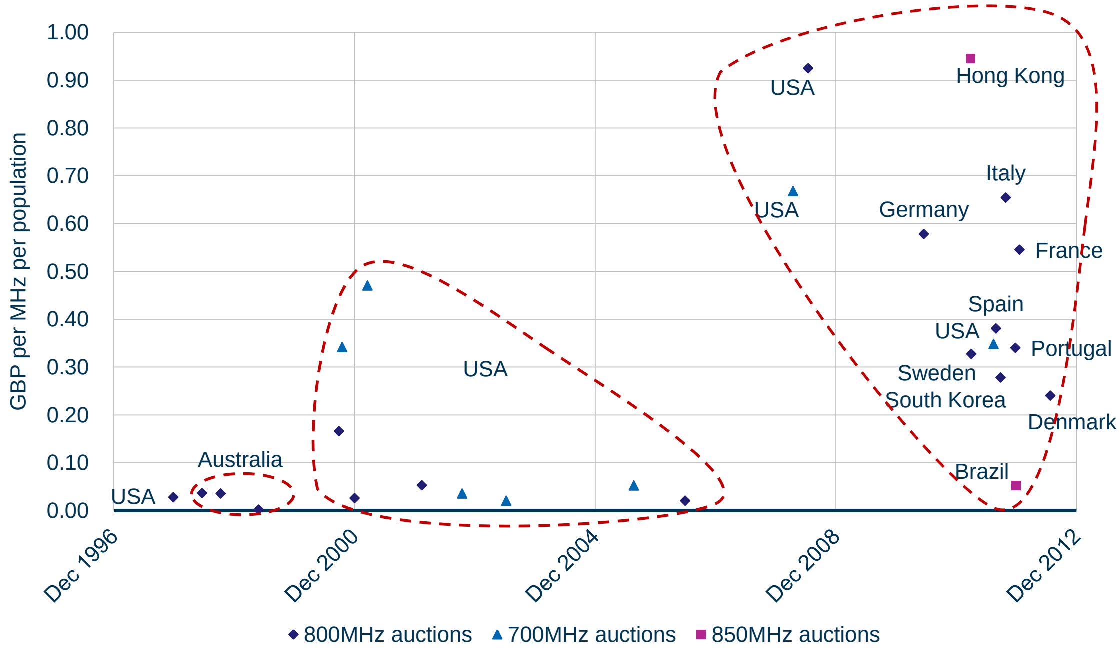
	Annualised value per MHz for 2×5MHz (GBP million)	Annualised value per MHz for 2×10MHz (GBP million)	Annualised value per MHz for 2×15MHz (GBP million)
Base case	2.21	**1.58**	1.18
Low active offloading	3.15	**2.35**	1.81
High active offloading	1.69	**1.16**	0.85
Low HetNet improvement	2.55	**1.84**	1.56
Low LTE spectral efficiency	3.71	**2.77**	1.24

While we have run these scenarios, we feel that the assumptions of low active offloading and low LTE spectral efficiency are unlikely to be justifiable.

5.1.4 Comparison against international benchmarks

Based on international benchmarks we have calculated an LCA opportunity cost of the 700MHz spectrum. This is based on a benchmark of the prices paid for 800MHz spectrum in Europe, and 700MHz and 850MHz spectrum in the Asia–Pacific region and parts of ITU Region 2. The full set of available benchmarks taken from past auctions is illustrated in Figure 5.28 below on a ‘per MHz, per head of population’ basis. This normalisation is necessary in order to directly compare the values.

Figure 5.28: Benchmarks of 700MHz, 800MHz and 850MHz spectrum values [Source: Analysys Mason, 2012]



We believe that spectrum in these frequency bands are likely to be of broadly similar value to operators. It is possible that 700MHz spectrum may be worth less in Europe than the amounts which have been paid for 800MHz spectrum because coverage savings of using low-frequency spectrum for LTE have already been achieved by operators. However, it is also possible that the value of 700MHz spectrum may be higher than for 800MHz spectrum due to the potential for even wider international harmonisation of the band. We therefore consider that, on balance, using benchmarks across these bands is an appropriate approach.

Our approach to the benchmark calculation can be split into four stages (each of these is described in further detail in Annex C):

- selecting appropriate marginal bidder value benchmarks
- adjusting to unencumbered lot values
- calculating GBP/MHz/annum figure for the UK based on full spectrum value
- adjusting full value estimate to a technical value estimate; that is an adjustment from the DP value to the LCA value.

It is estimated that for the 700MHz band the proportion of the full value, which is technical value, is likely to be between 20% and 50%, with a value towards the middle of this range most likely, which from our selected benchmarks implies an opportunity cost of the 700MHz band in alternative use in the range of GBP0.8 million to GBP1.9 million per MHz for LCA.

As discussed in Section 5.1.3, we consider that 2×10MHz per (generic) operator is the appropriate 700MHz spectrum allocation to consider and our base case valuation of GBP1.58million per MHz per annum lies within the estimated range.

Meanwhile if we assume 2×10MHz to be the relevant spectrum increment for our generic operator, our sensitivity analysis demonstrates a range of possible valuations from GBP0.75 million to GBP1.84million, similar to that of our benchmarking based valuation set out above. Similarly, a consideration of a change in the quantity of spectrum received by the generic operator with all parameters at their base case level gives a valuation range of GBP1.18 million to GBP2.21 million. Allowing for a change in both the amount of spectrum and the parameters gives a valuation range of GBP0.57 million to GBP2.55 million.

5.2 Opportunity costs of other alternative uses

There are various other spectrum users who might have a value for the DTT spectrum in an alternative use, including dedicated PMSE, PBR and Fixed links usage. We consider each of these in turn below.

PMSE

PMSE could be considered an alternative use in the DTT spectrum bands if it were to have one or more dedicated channels as opposed to making use of the interleaved spectrum, as it currently does. As shown in the results from Section 4.1.2 where we considered interleaved spectrum PMSE own use scarcity, there is no excess demand for PMSE within the DTT spectrum band even allowing for it to co-habit the band with DTT and local TV services.

This conclusion of no excess demand means that were an entire additional channel to be dedicated to exclusive PMSE usage, additional cost savings to the PMSE users would only arise if PMSE equipment for use in the DTT spectrum were cheaper than that for use elsewhere. As there are no notable cost differentials for PMSE equipment between equipment using dedicated DTT spectrum and other spectrum (including DTT interleaved), the opportunity cost would be zero. Thus, dedicated access to the band would not be a viable alternative use in terms of the opportunity cost.

We do note however that there is a risk that PMSE could become increasingly squeezed as the supply of suitable spectrum decreases following 800MHz allocation to mobile and the potential allocation 700MHz to mobile in the future. If this were to be the case then conclusions on excess demand for PMSE services may need to be re-evaluated.

PBR

Private business radio (PBR) is most frequently used for inter-employee communication, as well as for military or public safety purposes. The licences are generally allocated by geographical area corresponding to the area in which the business operates. While, national PBR licences have been allocated, the majority of PBR use is for small user bases concentrated around particular locations (e.g. taxi firms).

Historically, UK PBR use has been concentrated in the VHF bands which is harmonised across Europe for PBR usage. The lack of harmonisation for PBR in the DTT bands is likely to result in difficulties arising due to incoming interference from broadcasting services using the same spectrum in neighbouring countries, giving rise to high levels of interference into alternative UK uses, particularly in border areas. The 2009 Ofcom PMSE report[43] indicated that there were unassigned channels identified for PBR at the time of the report. As such PBR service providers are likely to choose to locate their services in the harmonised PBR identified channels as opposed to the DTT spectrum resulting in zero cost savings to locating in the DTT spectrum and hence a minimal or zero opportunity cost.

Fixed links

Fixed-link systems operate a wireless connection between two fixed points using directional antennas to form an (often permanent) link. These systems can operate across a range of frequencies, with current licences for frequencies from 450MHz to as high as 86GHz. In 2005, Analysys Mason produced a study for the Independent Audit of Spectrum Holdings.[87] This report included forecast demand to 2025 for spectrum below 15GHz for fixed links and concluded that congestion was only likely in the London area in 2010 in the 7.5GHz and 13GHz fixed links bands. Therefore, we only anticipate additional demand in the 7–12GHz range. As such we would expect the opportunity cost of the DTT spectrum to fixed terrestrial link service users to be minimal or zero.

5.3 Summary of opportunity costs for DTT spectrum in alternative uses

While we have considered a number of alternative uses for the DTT spectrum, our analysis has shown that it is only use of this spectrum for the provision of mobile services that has an opportunity cost which is likely to exceed the own use opportunity cost for DTT.

We have calculated the annualised value per MHz of spectrum using the LCA methodology and tested the sensitivity of this to a variety of different assumptions relating to the key inputs. The opportunity costs calculated and discussed in Section 5.1.3 are summarised in Figure 5.29 below.

87 “Spectrum demand for non-government services 2005–2025”

Figure 5.29: Opportunity costs for 700MHz spectrum for mobile broadband services [Source: Analysys Mason, 2012]

Sensitivities	Annualised value per MHz for 2×5MHz (GBP million)	Annualised value per MHz for 2×10MHz (GBP million)	Annualised value per MHz for 2×15MHz (GBP million)
Higher low-frequency spectrum	1.02	0.75	0.57
Late 700MHz launch (2026)	1.54	1.02	0.73
High WACC (10.4%)	1.63	1.15	0.86
High active offloading	1.69	1.16	0.85
Mid WACC (9.3%)	1.89	1.34	1.00
High starting sites (18 500)	2.12	1.50	1.07
Switched 800/900 spectrum	2.20	1.55	1.16
High 2.6GHz spectrum (2×20MHz)	2.22	1.57	1.17
Base case	2.21	**1.58**	1.18
Low starting sites (16 000)	2.33	1.69	1.28
Early 700MHz launch (2018)	2.35	1.70	1.29
Ofcom MLRIC asset costs	2.49	1.75	1.31
Low HetNet improvement	2.55	1.84	1.56

We feel that the most appropriate opportunity cost to form our base case is that for a generic operator in the base case with 2×10MHz of spectrum.

6 Opportunity cost in own use for DAB spectrum

This section discusses the opportunity cost calculations for the DAB spectrum in own use. The remainder of the section is set out as shown in Figure 6.1 below.

Figure 6.1: Map of Section 6 [Source: Analysys Mason, 2012]

6.1 Introduction

In this document we focus on the DAB band of Channels 10B to 12D (approximately 211–230MHz) plus Channel 5A (174–176MHz). Radio multiplexes (or ensembles) can be considered as either national or local, with different transmission methods appropriate depending on this distinction. For example, the BBC operates its national radio network via 229 BBC-owned SFN transmitters, but operates its local radio network via local commercially-operated transmitter sites.

Only two national MUXs exist (operating in Channels 12B and 11D/12A), whereas currently 48 local DAB ensembles operate throughout the UK spread amongst the other allocated channels. The coverage of each type of MUX layer is shown in Figure 6.2.

	National PSB coverage	National COM coverage	Local coverage
June 2011	92.2%	84.6%	66.2%
Estimated at potential radio switchover (2015)	97%	90.9%	90%

Figure 6.2: Current and forecast coverage of each type of MUX layer [Source: Analysys Mason, 2012]

Whilst confirmation of full digital radio switchover or dates at which it will happen are yet to be established, the timetable is expected to be accelerated beyond initial plans. The exact costs of the switchover are not public, but we note that a 2009 report by PWC estimated the net present value of the benefit to the economy from a full digital radio switchover to be in the region of GBP437 million.[88] PWC estimates an annual saving in transmission costs of GBP23.9 million due to not having to run an FM network in parallel with DAB. The largest cost to the economy is the cost of switching consumer equipment, especially in-car DAB receivers. To address this uncertainty of timing we have modelled four potential digital switchover scenarios, consistent with recent modelling by the Department for Culture Media and Sport (DCMS), as detailed later.

We have identified four potential responses by DAB MUX operators to a loss of spectrum from 2015 onwards, and model each of these to find the opportunity cost under both LCA and DP approaches.

As with DTT spectrum, these different responses are hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum. We note that in the future these options may change and some may no longer be applicable, whilst new options may exist, for example due to technological developments. However, at this point in time, the options listed below are an aid to help us to derive the economic value of the spectrum.

We consider the four different responses to mitigate a loss of spectrum for each of four different radio DSO switchover scenarios, which we describe in Section 6.3. Prior to this we have

88 "Cost Benefit Analysis of Digital Radio Migration", PwC for Ofcom, 2009, See http://www.culture.gov.uk/images/publications/REDACTED_Ofcom_CBA_of_DRMigration_Final_Report.pdf

undertaken an initial analysis on the level of scarcity within the band, which is set out in Section 6.2.

6.2 Scarcity of DAB spectrum

In this section we investigate the level of excess demand from both existing and alternative uses of the DAB band. As discussed in Section 3.3, we consider three main questions for the determination of spectrum scarcity in the DAB bands. :

- Is the spectrum currently (or does it seem likely to become) heavily congested under its current own use?
- If the spectrum is not congested, is this due to an artificial limiting factor (for example the restriction of licences)?
- Is there a realistic alternative use of the spectrum, and if so, is there excess demand from any of these alternative uses?

Current own use services of the spectrum come from DAB MUX broadcasting (operating on Channels 11B to 12D) and potential alternative usage comes from PMSE and PBR. We consider each of these below in turn. Unlike DTT, DAB mostly operates on SFNs; therefore we do not consider any interleaved spectrum opportunity costs.

We do not consider national or local digital TV services as a viable alternative use in this band, as described in Section7.1.

DAB services

Overall we do not consider there to be excess demand for DAB services in own use either currently or following any potential radio digital switchover (radio DSO).

Primarily this is due to the fact that only Channels 11B to 12D are currently being used for DAB despite Channels 10B to 11A being potentially available for use. Channel 11A was originally intended to hold the second national COM MUX run by the 4 Digital Group. However following the broadcaster ‘Channel 4’s withdrawal from the partnership (citing lack of demand), no other group has moved in to take over the spare MUX. Recently Ofcom was quoted as saying that they were not planning to re-advertise the licence, however “continue to monitor levels of interest from potential applicants”[89], which also indicates a current lack of demand.

One of the key drivers of DAB future demand could be radio DSO, with the majority of analogue stations that don’t already simulcast on DAB requiring additional MUX slots or be forced to close. In our calculations however we feel that the majority of these stations (which tend to be small regional or large local stations) could be accommodated on a single DAB channel operating multiple local MUXs. While there is also a possibility of a combined radio market under digital

89 See: http://radiotoday.co.uk/2011/11/digital-2/

being more attractive for stations, and so demand increasing, we believe that any effect will likely be small.

We also note the recent news of the closure of the regional MXR DAB multiplexes in 2013, with the broadcast stations intending to move to smaller local MUXs[90]. As these local MUXs will carry differing local services they are not able to reuse spectrum over such large areas, thus this move effectively loses the spectral efficiency gained through larger SFN networks. This news implied that the key industry players[91] do not feel spectrally limited, and do not see themselves becoming limited in the foreseeable future.

We note that the lack of spectrum scarcity is a different conclusion to that found in the Aegis–Indepen report[92] published in 2005, which found that there “appears to be demand for further commercial [DAB] multiplexes, particularly at national and regional level”, however we consider that this difference is due to the different outlook for DAB seen today compared to that predicted in 2005.

PMSE services

As in Section 4.1.2, we have made use of the structure of our excess demand for PMSE assessment from the 2009 Ofcom ‘Opportunity cost and AIP calculations for spectrum proposed for award to a band manager with obligations to PMSE’ report[43] in our assessment of scarcity. In this document the DAB spectrum bands we are interested in fall into the definition of ‘Band III’ from that report.

In 2009, only infrequent insufficient capacity at large events was flagged as cause for concern about scarcity. However, the overall conclusion was that there was no scarcity within Band III.

Between 2008 and 2012, the JFMG database shows a significant reduction in both assignments and assignment days within the relevant Band III. As such we feel that maintaining the 2009 conclusion of no excess demand is appropriate.

	2008	2012
PMSE assignments	142	55
PMSE assignment days	37114	2492

Figure 6.3: Band III PMSE assignments [Source: JFMG assignment database, 2012]

We do note however that there is a risk that PMSE could become increasingly squeezed as the supply of suitable spectrum decreases following 800MHz allocation to mobile and the potential allocation 700MHz to mobile in the future. If this were to be the case then conclusions on excess demand for PMSE services may need to be re-evaluated.

90 See: http://radiotoday.co.uk/2012/09/regional-mxr-digital-multiplexes-to-close/

91 MXR multiplexes are owned by Global Radio, Real and Smooth Ltd and Arqiva.

92 ‘Study into the potential application of Administered Incentive Pricing to spectrum used for Terrestrial TV & Radio Broadcasting’, Indepen and Aegis on behalf of Ofcom, October 2005.

PBR/fixed link services

As in our discussion of alternative uses for DTT spectrum in Section 5.2, we have considered the conclusions of the 2009 Ofcom PMSE report[43] with regards to scarcity.

We have first looked at scarcity of spectrum for PBR services in the DAB bands. The report states that “there are currently a large number of channels identified for PBR that are currently unassigned” in Band III and concludes that there is no excess demand for the alternative use in the band group. We note that this may not be the case for PBR across all spectrum, for example in the VHF spectrum which is outside the scope of this report.

As for the DTT spectrum discussed in Section 5.2, the findings of the 2005 Analysys Mason study for the Independent Audit of Spectrum Holdings,[87] suggests that the DAB spectrum is outside of the 7–12GHz range in which additional demand for fixed links is expected to arise. Thus we conclude that there is unlikely to be any excess demand.

6.3 Overview of opportunity cost of DAB in own use

6.3.1 Overall approach

The value in ‘own use’ for DAB is derived from the cost to DAB MUX operators of providing an identical (LCA) or potentially reduced (DP) service given a loss of spectrum. Where spectrum is not considered scarce, such as for DAB, these values would represent the opportunity costs were the spectrum to be considered scarce. Throughout the remainder of this section, when we refer to the opportunity cost of the DAB spectrum we are referring to this value to the current users.

For both the LCA and DP approaches we assume that coverage remains at the agreed post-switch-over levels for both national and local MUXs. However, unlike for DTT, the calculated opportunity cost is not split by PSB and COM MUX because for DAB the PSB operator (BBC) uses COM MUXs for its local stations so is integrally linked with the local COM MUXs.

Our DAB modelling considers spectrum loss in increments of 1.5MHz channels. However, where a response to a spectrum loss would allow for greater amounts of spectrum to be vacated at lower incremental costs, we account for this by dividing the total costs by the total spectrum vacated. Given the vast difference in usage (and coverage achieved) between the two channels used for the national MUXs and the 5 channels used for the local MUXs, we have in the majority of cases calculated the opportunity costs for an average channel. Additionally, as with DTT, the WACC for a DAB MUX operator is assumed to be equivalent to Arqiva’s regulated WACC of 10.4% pre-tax nominal.

We have identified 4 potential responses by DAB MUX operators to a loss of spectrum, and have modelled each of these to find the LCA. As described above, these different responses are hypothetical scenarios designed to allow the modelling of the theoretical opportunity costs of the spectrum.

The 4 different responses modelled (including 2 separate responses involving switches to alternative platforms) are:

- Implementing a technology upgrade to provide increased capacity within the remaining spectrum. We consider the most likely option to be upgrading the DAB transmission technology to DAB+, which would bring the UK in to line with Germany, Italy and Switzerland.
- The migration to use a different spectrum channel, which due to the typical tuning range of DAB receivers could ideally be any spare spectrum within VHF Band III.
- Migration of users from the DAB platform to an FM platform.
- Migration of users from the DAB platform to a DRM+ platform. We consider FM or DRM+ to be the closest relevant alternatives to DAB due to their similar characteristics, though note that a move to DRM+ could probably only occur if the FM spectrum had been vacated as part of radio DSO.

The possibility of a move to a satellite radio service[93]is not considered given the large cost of launching a satellite, or renting capacity from an existing satellite, and the significant radio receiver costs involved. Similarly, moving to the delivery of digital radio over the Internet is not considered as it would likely preclude good-quality mobile reception (e.g. in cars) unless a specific network was to be developed that enabled better mobile coverage.

It is possible that the existing DAB infrastructure could be migrated to use lower-power SFNs compared to the higher-power transmission used at present. This would allow better coverage in-fill as well as improving scope for delivery of local radio over DAB. While this is expected to happen at the regional level, which is already becoming more localised[94], it would be prohibitively expensive at the national level, due to the large number of new sites and increased on-going opex requirement and as such we do not consider this alternative below.

While DAB MUXs can operate via either SFN or MFN transmitters, in a similar fashion to DTT, the majority of UK DAB transmitters operate using SFNs. As such there are limited possibilities of spectrum savings by switching from MFN to SFN, as was considered for DTT.

One of the largest uncertainties in modelling the opportunity costs for DAB in 2015 is the state of the digital radio switchover at that time. To address this uncertainty we have modelled 4 potential digital switchover scenarios, as discussed in DCMS's recent report on the '*Cost-benefit analysis of radio switchover'* (CBA report)[95]:

93 With distribution to cars and portable receivers, as is seen in the USA with Sirius/XM.

94 "The industry (commercial and BBC) has agreed that the best way forward for digital roll out and to speed up coverage, the focus should be on local and national multiplexes. Therefore there is reducing demand for carriage on regional multiplexes" See: http://radiotoday.co.uk/2012/09/regional-mxr-digital-multiplexes-to-close/

95 See http://www.culture.gov.uk/images/publications/CBA_Radio_Switchover_Methodology_Report_July12.pdf

- Counterfactual: No digital switchover
- DSO Scenario 1: UK-wide switchover in 2015
- DSO Scenario 2: UK-wide switchover in 2018 following market trends (i.e. at a time when DAB is assumed to have reached similar coverage and listenership to FM)
- DSO Scenario 3: Phased nation-by-nation switchover (England switches in 2017, Wales in 2018 and Scotland and Northern Ireland in 2019)

Where the replacement of radio receivers is a part of the response a scenario-based approach has been used to find the cost under different replacement options. This is similar to our approach of using 4 CPE replacement scenarios for DTT. For DAB, we consider the following 3 radio replacement (RR) scenarios:

- RR Scenario 1: Just primary household DAB radios
- RR Scenario 2: Primary household DAB radios and all DAB car radios (we consider this to be the most likely scenario)
- RR Scenario 3: All household DAB radios and all DAB car radios

6.3.2 Market sizing

In order to assess the radio receiver replacement requirements for each of the three RR scenarios discussed above, we have built a market model for DAB radio equipment. This model considers two key components: the number of household DAB receivers; and the number of car DAB receivers. Each of these two sources of DAB equipment is modelled independently as discussed below.

DAB household radio receivers

To calculate the number of primary household radio receiver sets, the number of UK households (as in the DTT market model) is multiplied by DAB household penetration figures. Historical DAB penetration is taken from Radio Joint Audience Research (RAJAR) statistics and future trends from the DCMS's CBA report under each DSO scenario. For comparison, the total number of analogue receivers is also modelled.

The total number of DAB receivers (and analogue receivers) is calculated using the radio sales per year from Ofcom's 2012 Communications Market Report. It is assumed that 8% of existing receivers are disposed of annually, either from breakage or through being upgraded. Of these sales, a proportion of receivers are modelled as already being DAB+ compatible (i.e. can immediately be used for DAB+).

Where required, the 2010 regional data is used to find penetration by each UK nation, with the relative penetration between regions assumed to be constant over time. The overall flow of the calculation is illustrated in Figure 6.4 below.

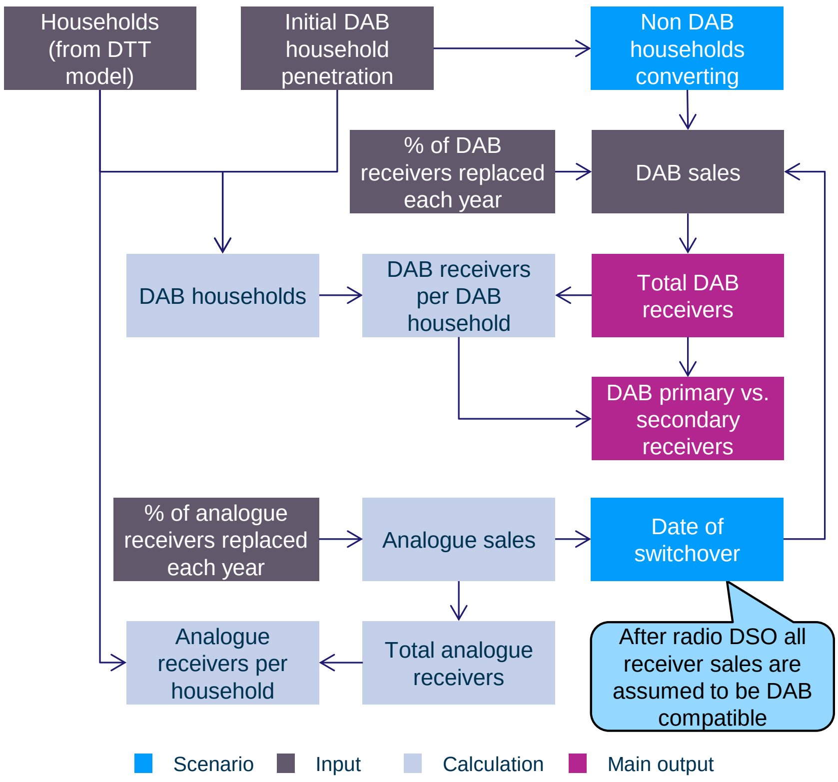


Figure 6.4: Flow diagram of the DAB household radio market model [Source: Analysys Mason, 2012]

DAB car radios

To calculate the number of cars with DAB radios we calculate the proportion of cars that are bought each year with DAB capability and the number of analogue car radios that are converted. This requires information on the total population of analogue only cars (which is the total number of cars less cars with DAB capability).

The total number of cars is calculated using Department for Transport (DFT) historical and forecast figures for total cars on the road. Historical data on the number of car sales is based on DFT data, and is forecast to grow in line with the number of households. The difference between the cumulative car sales and total cars forecast to be on the road is the number of cars that are removed from circulation. However, it is assumed that any DAB car radios/convertors are moved onto other existing cars and so not scrapped.

Of the total car sales, a percentage are assumed to be sold already including DAB sets, on top of which we assume that 1% of existing car radios are converted annually prior to DSO (or until all cars are DAB compatible in the DSO counterfactual scenario).

Our forecast of DAB equipped car sales is driven by the Society of Motor Manufacturers and Traders (SMMT) commitment that 100% of new cars sold by the end of 2013 will include DAB radios. In addition we have assumed that no cars were equipped with DAB radios prior to 2008.

Where a national breakdown is required, the historical sales of cars, by region, are assumed to scale with our forecast of the number of households per region. The overall calculation flow is illustrated in Figure 6.5 below.

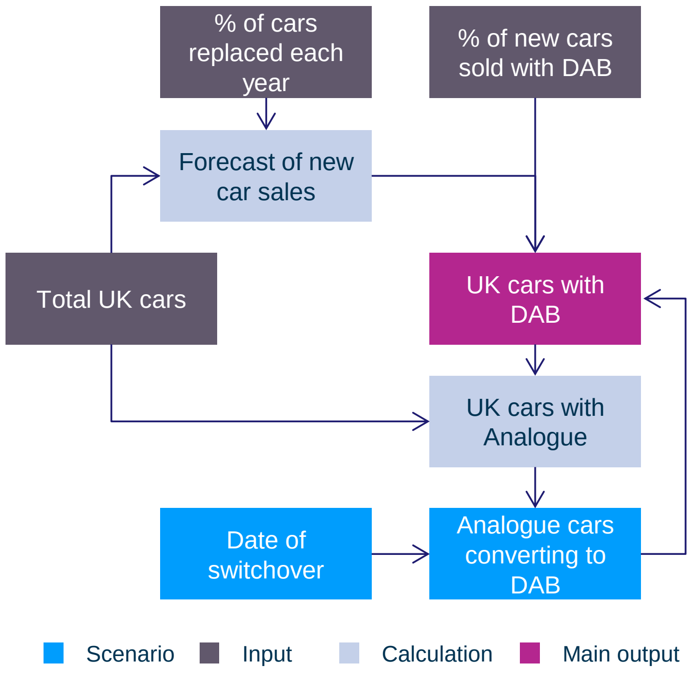


Figure 6.5: Flow diagram of the DAB car radio market model [Source: Analysys Mason, 2012]

6.3.3 Radio DSO scenarios

DAB households

We use figures from the DCMS's CBA report to forecast the percentage of households converting to DAB each year under each different radio DSO scenario. The sales levels are adjusted in each of our four switchover scenarios, with analogue radio sales assumed to drop to 0 once the DSO date is announced (which varies by scenario). Following DSO the total number of DAB households just grows gradually with household growth as can be seen in Figure 6.6 below.

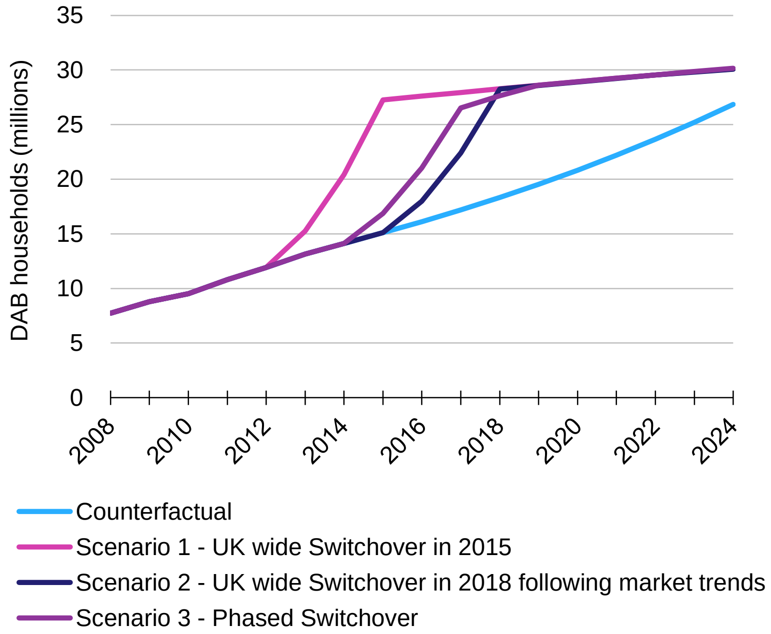


Figure 6.6: Number of DAB households under different switchover scenarios [Source: Analysys Mason, 2012, DCMS, 2012]

However the total number of DAB radios, including secondary sets is higher in DSO Scenario 1. This is because the number of non-primary sets accumulates over time, meaning an earlier DSO leads to more DAB receivers overall (this assumes that radio receivers do not have a defined saturation point that is reached within the timeframe of the model).

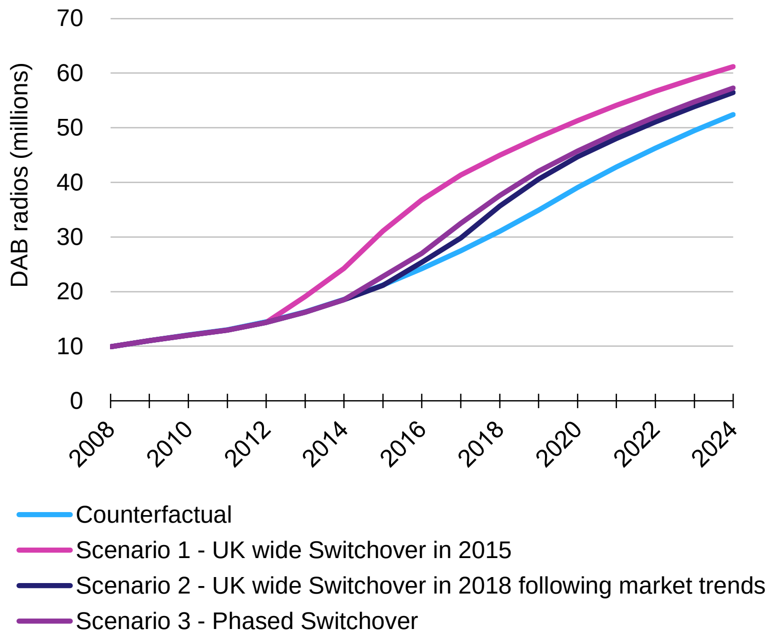


Figure 6.7: Number of DAB radios under different switchover scenarios [Source: Analysys Mason, 2012, DCMS, 2012]

DAB cars

We use the DCMS's CBA report figures for the percentage of cars converting to DAB each year in each different DSO scenario The difference between the number of cars using DAB radios and the cumulative sales of new cars with DAB radios pre-installed, is assumed to be equivalent to the number of DAB car radio convertors sold. As can be seen in Figure 6.8, the number of DAB radios flattens out in each scenario once all cars are converted, and then only grows at the same rate as the total number of cars.

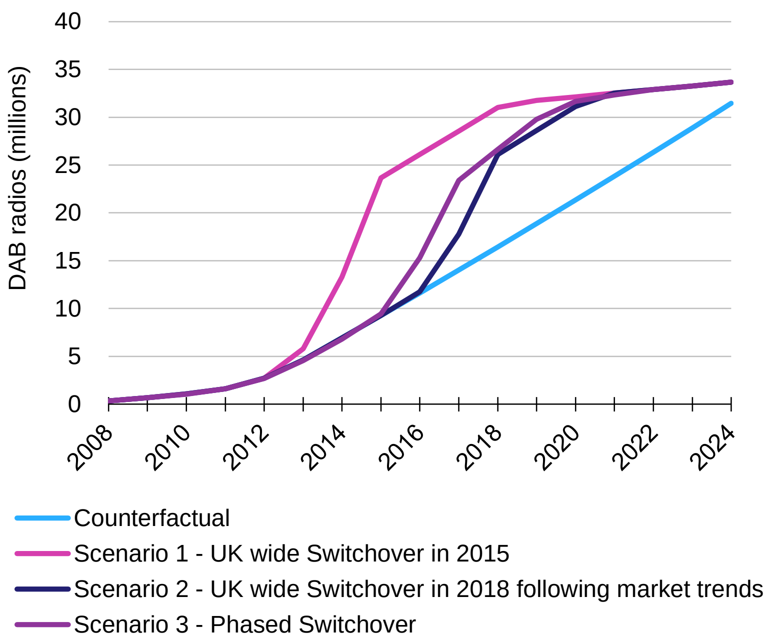


Figure 6.8: Number of DAB cars under different switchover scenarios [Source: Analysys Mason, 2012, DCMS, 2012]

Sites and transmitters

Radio stations are split into national, semi-national and local categories; with the number of DAB only, analogue only and DAB & analogue stations in each category mapped over time under each radio DSO scenario.

It is assumed that after DSO all stations currently on both DAB and analogue move to just transmitting on DAB, however a proportion (30%) of local analogue-only stations remain transmitting only on analogue in line with the current DSO plans.

Once the number of MUXs required under each DSO scenario is calculated, the required number of transmitters is determined by scaling up from the counterfactual case. The number of DAB sites is grown over time based on the current coverage targets.

DSO synergies

While we note that in practice possible synergies could be achieved if the spectrum mitigation happened to coincide with radio DSO[96], we believe it is not appropriate to include these 'fortunate timing' effects in the calculation of opportunity costs.

6.3.4 DP opportunity costs

As discussed in Section 3.4.2, the DP opportunity cost (considered only in 'own use') is the difference between the MUX operator cashflow of delivering a service using the current spectrum and the profit-maximising production method, following the loss of an amount of spectrum, where the same level of output does not need to be maintained.

To model this DP value we use similar approaches to the modelling of the LCA value under the equivalent mitigation strategy. However, we also consider the affect that allowing the COM MUX operators to reduce their service output (should they wish to) could have on the cost of mitigation.

Two areas we consider as having scope for service reduction are in the subsidy of radio receiver conversion costs and the cost of transferring across each DAB station to a new platform.

We model the reduced subsidy for replacement radio receivers by assuming that operators offer a proportional subsidy rather than full replacement of equipment. This subsidy can vary from 0%, where users have to fully fund their own replacement equipment, to 100%, which is identical to in the LCA approach.

The trade-off for operators offering a lower radio receiver subsidy is that the number of people who transfer across to the new platform may reduce. This in turn would reduce the number of users compared to the current level. This would likely impact advertising revenues of the radio stations which would reduce their WTP for MUX slots.

The amount of people leaving at a given level of subsidy is calculated using the approximation of a demand curve for 'DAB versus analogue', derived from DCMS commissioned WTP research from London Economics. The London Economics WTP data is used as an upper bound in the DCMS report, since the data looks at the summation of WTP for individual attributes but studies have shown that this overestimates consumers' WTP for a specific bundle of various attributes. We consider it as closer to a lower bound in our analysis because the remaining analogue service would be minimal, as it is likely to be reduced to just local stations, following radio DSO.

The demand curve in Figure 6.9 below shows the proportion of radio listeners who would be willing to incur different incremental costs each month to use DAB rather than analogue radio.

96 This could include sharing marketing costs with DSO and ensuring any DSO subsidised CPE sales are DAB+/DRM+ compatible.

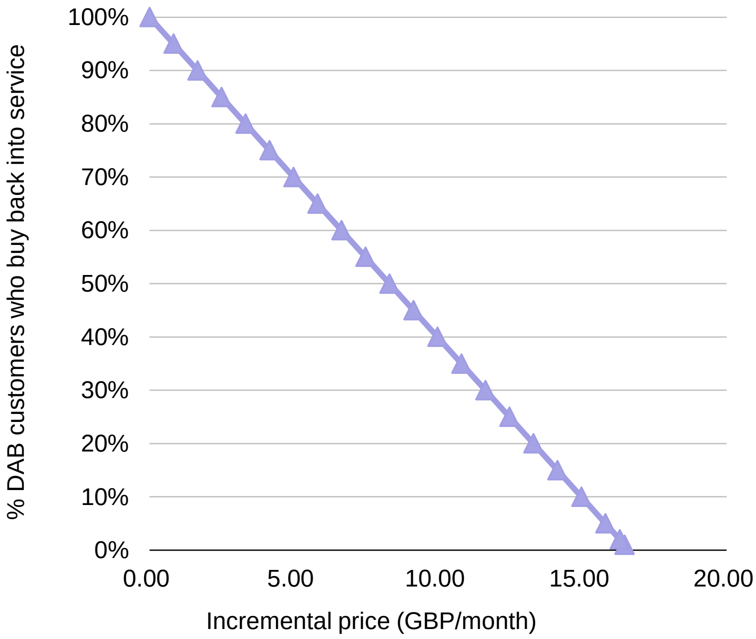


Figure 6.9: Approximated demand curve for DAB versus analogue [Source: Analysys Mason, 2012; DCMS, 2012]

The total revenue lost by MUX operators (i.e. the reduction in the MUX slot revenue), is assumed equivalent to the amount of DAB advertising revenue lost by the broadcasters. It is assumed that radio advertising is allocated on the basis of both primary household radio sets and car radio sets. This means that the amount of advertising revenue lost is calculated as the total DAB advertising revenues multiplied by the percentage of lost primary household sets and car radios.

Given the assumption that advertising revenues are allocated on the basis of primary household radios and car radios, we note that the DP approach is always incremental to LCA RR Scenario 2. In other words, no subsidy is provided to households for replacement of secondary (or above) DAB sets because there is no financial benefit in doing so.

6.4 DAB own use LCA and DP opportunity cost methodologies

In this section we consider in turn the costs of each of our 4 potential responses by DAB MUX operators to a potential loss of spectrum under both the LCA and DP approaches.

6.4.1 Upgrade of radio MUXs to DAB+

Currently DAB radio is broadcast via COFDM using the MPEG-1 Audio Layer II (MP2) codec, allowing multiple radio stations to be transmitted in a single MUX grouping. The key future upgrade path for DAB is DAB+, which uses a more efficient encoding system and better error correction codes, though signals cannot be received by DAB-only receivers.

This incompatibility is likely to restrict its use in the UK for the foreseeable future, and the Government has stated that transition to DAB+ will only occur once the majority of UK digital radio receivers are DAB+ compatible.[97]

In our LCA analysis we consider that a reduction in allocated spectrum could be mitigated by an early move to DAB+. This would reduce the number of MUXs required to provide the same number of radio stations at the same quality, and hence also reduce the spectrum requirements.

Assuming a coding efficiency increase of 200%[98], under our counterfactual non-DSO scenario the two national MUXs could be reduced to a single MUX and still have space for some of the semi-national stations. It is also assumed that with necessary area aggregation the 48 separate local MUXs (across 5 channels) could be compressed to under 20 regional MUXs operating across 2 channels, though we note that this aggregation might be non-trivial in practice.

LCA approach

The cost of upgrading the whole DAB platform to DAB+ under the LCA approach is determined by 5 key drivers:

- the costs of household radio set conversion from DAB to DAB+ (including a possibly loss form advertising in RR replacement Scenario 1)
- the cost of re-engineering the broadcast network
- the costs of frequency re-planning to fully vacate the saved spectrum
- the costs associated with publicity of the technology upgrade
- the savings made from reducing future DAB transmission costs.

The cost of radio receiver replacement, and/or conversion, is calculated using the number of DAB receivers which need replacing (determined by the radio receiver replacement scenario) multiplied by the unit cost for a radio receiver, and with a cost for marketing. The unit receiver costs are taken from retailers' prices (which are comparable to, but slightly below, the figures in the DCMS report). We have used figures of GBP60 for new DAB+ household radios and GBP69 for DAB+ car radio converters (including aerial). Any DAB+ compatible receivers, as determined by the market model, do not require an upgrade.

The cost of the required publicity is assumed to be equivalent to the radio DSO advertising costs used in the DCMS CBA report (based on cost estimates by UK DRUK). These costs are then distributed across the relevant switchover time scale.

The broadcast network costs consist of a required upgrade of audio coders from DAB to DAB+ for each MUX still used following the upgrade. It is assumed that no site or transmitter conversion/re-tuning is required. This is because the transmitter will be fed using the Ensemble Transport

97 "Digital Radio Action Plan", DCMS, 2010, See http://www.culture.gov.uk/images/publications/digitalradioactionplan_vs1.pdf

98 See: http://www.worlddab.org/introduction_to_digital_broadcasting/dab_plus_digital_radio/how_dab_plus_works

Interface (ETI) which is the same whether it is carrying DAB or DAB+ coded data, and most modern transmitters can change channel easily (if required due to re-planning).

As discussed above, the amount of spectrum saved is calculated assuming a broadcasting efficiency increase of 200%. The absolute of spectrum saving depends on the DSO scenario, with the radio stations moved to DAB under radio DSO leading to an increased number of DAB MUXs, so an increase in the spectrum saved due to the upgrade:

- under the counterfactual scenario 6MHz of spectrum is vacated, with national MUXs compressed from 2 channels to 1 channel and local MUXs compressed from 5 channels to 2 channels
- under each DSO scenario 7.5MHz of spectrum is saved, with national MUXs still compressing from 2 channels to 1 channel but local MUXs compressed from 6 channels to 2 channels.

The calculation flow is illustrated in Figure 6.10 below.

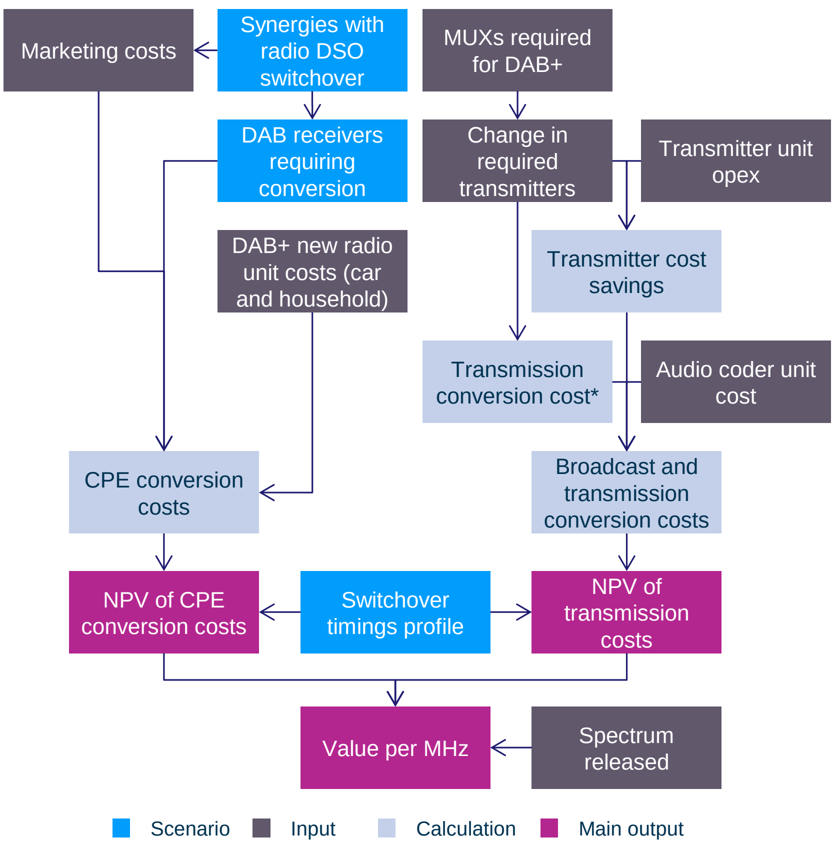


Figure 6.10: Flow diagram of the DAB+ upgrade LCA methodology [Source: Analysys Mason, 2012]

The most significant cost of the upgrade to DAB+ is for radio receiver conversion, with conversion costs further increased under DSO Scenario 1, where switchover from analogue to DAB is completed before the DAB+ upgrade begins.

DAB advertising revenue is assumed to be allocated on the basis of primary household radios and car radios. Therefore in RR Scenario 1 where only primary household receiver replacement is subsidised, the costs take into account any car radios which leave the service (calculated in the same way as for the DP approach), and therefore the associated revenue loss from advertising.

The cost associated with upgrading to DAB+ is shown in Figure 6.11 below.

Figure 6.11: LCA cost for DAB+ technology upgrade [Source: Analysys Mason, 2012]

Mitigation strategy	Counterfactual (GBP thousand/ MHz/annum)	DSO Scenario 1 (GBP thousand/ MHz/annum)	DSO Scenario 2 (GBP thousand/ MHz/annum)	DSO Scenario 3 (GBP thousand/ MHz/annum)
RR Scenario 1	5642	8008	5108	5663
RR Scenario 2	9306	18 227	7876	9208
RR Scenario 3	11371	19 461	9356	10 437

We consider RR Scenario 2 to be most likely and all DSO scenarios to be equally likely. A further breakdown of the cost drivers for RR Scenario2 across all DSO scenarios is shown below in Figure 6.12.

Figure 6.12: Net present value breakdown into cost categories for LCA, RR Scenario 2, DAB+ technology upgrade case [Source: Analysys Mason, 2012]

NPV categories	Counterfactual (GBP thousand)	DSO Scenario 1 (GBP thousand)	DSO Scenario 2 (GBP thousand)	DSO Scenario 3 (GBP thousand)
Cost of radio replacement	755 951	1 886 395	801 510	941 091
Costs of re-engineering broadcast network	418	485	418	418
Costs of network re-planning	418	418	418	418
Costs associated with publicity	34 863	34 863	34 863	34 863
Loss from reduced users[99]	0	0	0	0
Loss (/savings) from transmission	-11 400	-11 738	-11 738	-11 738
Total	**780 250**	**1 910 423**	**825 471**	**965 052**
Spectrum released	6.0MHz	7.5MHz	7.5MHz	7.5MHz
Value/MHz/Annum	**9306**	**18 227**	**7876**	**9208**

99 Loss from advertising only occurs in RR Scenario 1, where the subsidy doesn't fully cover car radio equipment so some people leave the platform rather than migrating to DAB+.

Compared to the conversion of DTT to using DVB-T2 (as in Section 4.3), these costs per MHz are higher for several reasons:

- currently DAB+ compatible radios are more costly, with a DAB+ radio costing more than a DVB-T2 STB, though this cost may continue to fall as DAB and DAB+ receivers become more of a commodity rather than a luxury item
- following DSO, radio users will not be split amongst multiple service platforms unlike with TV split between cable, DTT and DTH, and as such every household with a radio will have a primary set that needs to be considered
- the current number of existing DAB+ compatible receivers is much lower as a proportion of total radio receivers than DVB-T2 compatible CPE as a proportion of total TV receivers. This is mostly down to consumers gaining no substantial benefit from buying a DAB+ set, whereas buying a DVB-T2 STB enables them to gain additional HD services[100].

However, the main reason for the seemingly high per MHz opportunity costs, when compared to DTT, is that converting to DAB+ only saves 6–7.5MHz of spectrum, whereas an equivalent technological upgrade for DTT to DVB-T2 saves 80MHz. Therefore similar levels of cost are spread over a much smaller amount of spectrum.

DP approach

In considering the DAB+ response under the DP approach, we use a similar methodology to the DAB+ LCA conversion model. However, under DP, the operator does not necessarily need to fully subsidise radio replacement but rather chooses to optimise the amount of subsidy given. As a lower subsidy would lead to some users leaving the platform, which in turn leads to reduced advertising revenues to radio stations, and reduced revenues for MUX operators, the operator would aim to minimise the combination of radio replacement subsidy cost and revenue loss.

The number of people that leave the platform is derived from the proxy ‘analogue to DAB’ demand curve as discussed above in Section 6.3.4. Also as discussed, the DP case is based on RR Scenario 2, with the LCA radio replacement costs scaled by the subsidy percentage to calculate the NPV. Marketing costs though remaining unchanged.

100 Currently most consumers only buy DAB+ compatible CPE because manufactures may only produce a single set to cover Europe rather tailoring the set to the specific country.

The approach is illustrated in Figure 6.13 below.

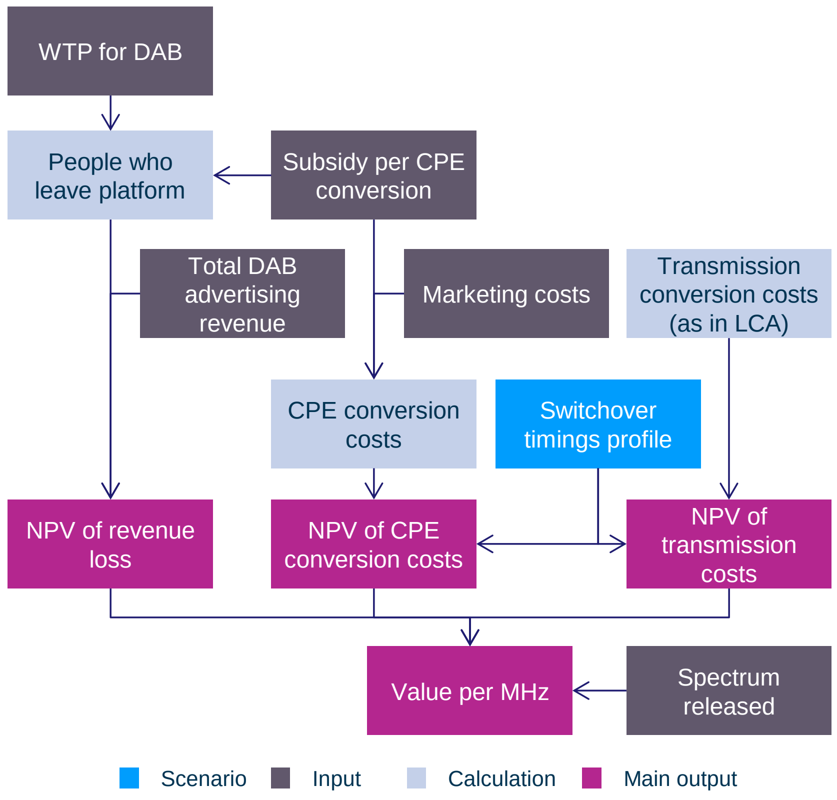


Figure 6.13: Flow diagram of the DAB+ upgrade DP methodology [Source: Analysys Mason, 2012]

For all DSO scenarios, we find that the optimal strategy is to not subsidise radio receiver replacement. Of the DAB users which would require additional equipment and therefore additional investment to stay on DAB+, circa 24% of primary household radios and 17% of car radios opt not to move to the new platform. This has a greater cost in some DSO scenarios, as the level of DAB specific advertising revenues differ depending on the status of DSO (as following radio DSO they also include analogue radio advertising revenues).

The result is that, whilst remaining very high, the DP spectrum loss mitigation costs are substantially lower than the equivalent LCA mitigation costs. The costs under the DP approach are shown in Figure 6.14 below.

Figure 6.14: Net present value breakdown into cost categories for DP, RR Scenario 2, DAB+ technology upgrade case [Source: Analysys Mason, 2012]

NPV categories	Counterfactual (GBP thousand)	DSO Scenario 1 (GBP thousand)	DSO Scenario 2 (GBP thousand)	DSO Scenario 3 (GBP thousand)
Cost of radio replacement	0	0	0	0
Costs of re-engineering broadcast network	418	485	418	418
Costs of re-planning	418	418	418	418
Costs associated with publicity	34 863	34 863	34 863	34 863
Loss from reduced users[101]	126 132	353 616	192 890	228 343
Loss (/savings) from transmission	-11 400	11 738	11 738	-11 738
Total	**150 431**	**377 644**	**216 851**	**252 304**
Spectrum released	6.0MHz	7.5MHz	7.5MHz	7.5MHz
Value/MHz/Annum	**1794**	**3603**	**2069**	**2407**

6.4.2 Migration of a channel's contents to a channel at an alternative frequency

Although Ofcom has asked us to consider the whole DAB band ranging from Channels10B to 12D plus 5A, current DAB services only operate on the 7 channels from 11B to 12D. As was discussed in Section 6.2, this is one of the reasons for our conclusion of lack of spectrum scarcity in the DAB band.

A possible spectrum-loss mitigation response is moving one or more of the currently used channels to areas of lower demand. When considering the opportunity costs of just Channels 11B to 12D these areas would include the other empty channels in the DAB band. As such we consider the cost of moving to either Channel 11A (the channel held for the second national COM MUX) or to one of the other unused DAB channels between 10B and 11B.

It is assumed that were DAB to seek to use alternative spectrum channels, it would have a higher opportunity cost than any incumbent PMSE/PMR usage in the channels concerned. Therefore we consider migration to such channels to be a valid response to a loss of spectrum, even if it may be more complicated in practice. This is consistent with the approach followed when considering the migration of DTT channels to the 600MHz band.

When considering the opportunity cost for moving the contents of a single channel we have calculated the cost for an average channel, rather than differentiated between channels primarily used for local services and those used for national services.

101 Loss from advertising only occurs in RR Scenario 1, where the subsidy doesn't fully cover car radio equipment so some people leave the platform rather than migrating to DAB+.

LCA and DP approach

The cost of moving a single channel in the DAB platform to a different frequency, under the LCA approach, is determined by 3 key drivers:

- the cost of re-engineering transmitters
- the costs of frequency re-planning to fully vacate the saved spectrum
- the costs associated with publicity of the technology upgrade.

As all current DAB radios can scan through the whole of VHF Band III, it is assumed that no replacement radio receivers are required in moving to use these different channels, unlike in the DTT channel move LCA. For this reason, the DP and LCA approaches both incur the same cost for this spectrum loss mitigation response.

Additionally, given that no receivers would need replacing and the services would continue to run in the same fashion as they currently do, it is likely that only a small marketing campaign would be required to raise awareness. This would primarily serve to inform users that they will need to perform an 'auto-scan' once broadcasting in the existing channel ceases.

To determine the cost of this smaller marketing campaign, we take the average cost per minute of a radio advertisement (calculated at GBP45 per minute) and assume a 60 day campaign of 1 minute per prime hour across each of the affected stations. We assume an additional 25% mark-up on this cost for creation and administration of the advertising campaign.

We have assumed that given the modern adaptability of most current DAB broadcasting transmitters and aerial systems, no additional costs would be incurred to change the channel transmitted on. However, at sites where more than one multiplex is radiated using a single antenna, a new (or re-tuned) combiner is needed. This is required on circa 70% of the sites with multiple MUX transmitters.

As this mitigation strategy only moves a single channel it will vacate 1.5MHz of spectrum, although it could potentially be applied to more channels with costs roughly scaling in proportion to the number of channels. The approach followed in our model is illustrated in Figure 6.15 below.

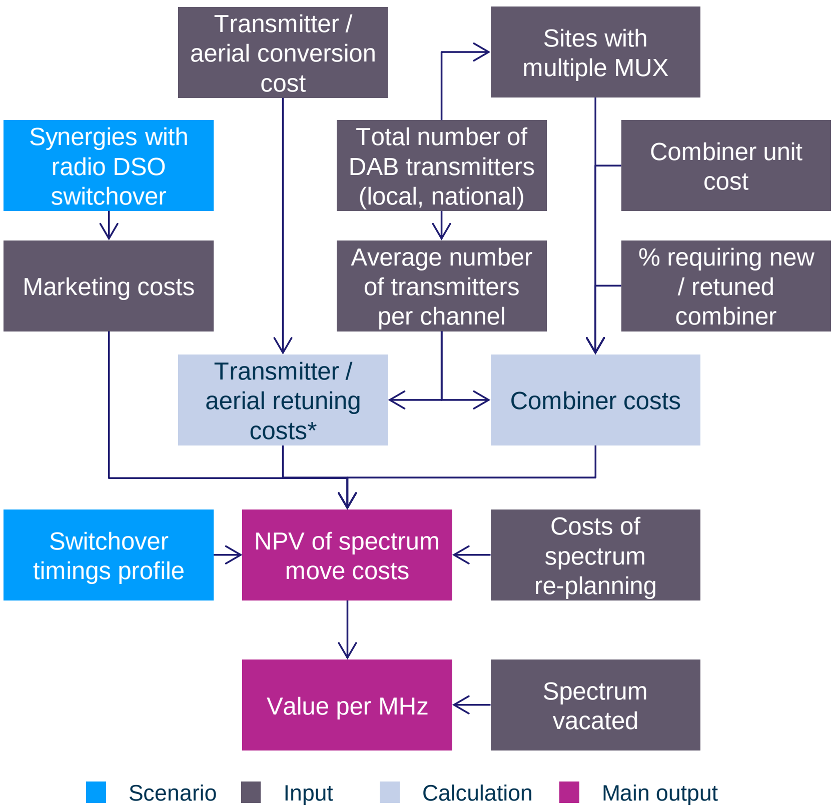


Figure 6.15: Flow diagram of the move of a DAB channel to an alternative frequency [Source: Analysys Mason, 2012]

As discussed above the cost, as shown in Figure 6.16 below, is calculated as the average channel cost, though we note that in practice the DAB channels with national services on would likely have a higher cost than those with local services on, due to:

- the larger number of transmitters operated on a single channel
- the increased difficulty in re-planning (and international agreement) of spectrum for the larger national service
- the increased cost per minute of advertising.

Figure 6.16: LCA and DP costs for move of a DAB+ channels to an alternative frequency [Source: Analysys Mason, 2012]

Mitigation strategy	*Counterfactual (GBP thousand/ MHz/annum)*	*DSO Scenario 1 (GBP thousand/ MHz/annum)*	*DSO Scenario 2 (GBP thousand/ MHz/annum)*	*DSO Scenario 3 (GBP thousand/ MHz/annum)*
Least cost alternative	98	101	95	96
Discounted profit	98	101	95	96

As is shown in our detailed breakdown of the costs in Figure 6.17 below, the main cost of moving a single DAB spectrum channel is likely to be the marketing campaign. It is possible that this cost could be reduced if combined with the radio DSO advertising campaign, for example in DSO Scenarios 2 and 3 where the timing overlaps. However we have decided it is not appropriate to take this influence of 'fortunate timing' into account in the calculation of opportunity cost, and therefore apply the same marketing costs across each DSO scenario. We note however that if marketing costs were reduced through combination with another spectrum change, the main cost of mitigation would then become the cost of spectrum re-planning and re-engineering of any transmitter combiners, both of which are very low.

Figure 6.17: Net present value breakdown into key factors for both LCA and DP, for move of a DAB+ channels to an alternative frequency [Source: Analysys Mason, 2012]

NPV categories	Counterfactual (GBP thousand)	DSO Scenario 1 (GBP thousand)	DSO Scenario 2 (GBP thousand)	DSO Scenario 3 (GBP thousand)
Costs of re-engineering TX	580	646	537	556
Costs of re-planning	418	418	418	418
Costs associated with publicity	1046	1046	1 046	1046
Total	**2044**	**2111**	**2002**	**2021**
Spectrum released	1.5MHz	1.5MHz	1.5MHz	1.5MHz
Value/MHz/Annum	**98**	**101**	**95**	**96**

This mitigation response is the LCA and is the lowest-cost DP case for all DSO scenarios. However if considering the band as Channels 10B to 12D plus 5A, and as such a spectrum loss mitigation alternative required a move of DAB channels outside of this range then it may become significantly harder to find a free appropriate band and so the costs may increase dramatically. We also note that there may be practical difficulties with this approach depending on the channels chosen to migrate to.

6.4.3 Switch of DAB stations onto the existing FM platform

Currently radio operates on both DAB and FM platforms, with several stations operating off both platforms. Following the proposed radio DSO it is thought that the FM platform will still exist for smaller local stations. For these reasons radio receivers are likely to remain FM compatible for the foreseeable future, and as such one possible method to mitigate reductions in DAB spectrum would be to move all stations over to the FM platform.

While we model the move to FM under all DSO scenarios, we note that under scenarios where DSO has already occurred, a move from DAB back to FM is not likely to be desirable.

LCA approach

The cost of switching a single channel in the DAB platform to the FM platform, under the LCA approach, is determined by four key drivers:

- the cost of additional FM transmission requirements
- the costs of frequency re-planning to fully vacate the saved spectrum

- the costs associated with publicity of the technology upgrade
- the savings made from reducing future DAB transmission costs.

It is assumed that no radio receiver replacement would be required, as all currently sold DAB sets are FM compatible and this is assumed to remain the case even after DSO, given FM's continued use for some local radio

In calculating the costs of transferring DAB stations to FM we have assumed that stations already present on the FM platform would not need transferring. It is assumed for DAB and FM networks with roughly equivalent coverage, 1.5x more transmitters and sites are required using DAB compared to FM (this is due to the higher diffraction loss at 220 MHz). However, on FM each additional radio station would require a separate transmitter, whereas for DAB only each MUX requires a transmitter (i.e. ~14 stations). This means that while the site costs decrease, the transmitter costs increase dramatically per station when using FM.

As there are no radio receiver costs, and little scale benefit from moving the whole platform, we assume only one channel is moved, and so this mitigation strategy vacates 1.5MHz of DAB spectrum. Given the significantly worse spectral efficiency in transmitting FM stations, it is likely that FM spectrum is not able to contain all the stations currently found on DAB, so a full scale move of all 7 DAB channels to FM may not be possible, or at least very difficult in practice.

As in the case of moving a DAB channel to a different frequency in VHF Band III, we have assumed the DAB channel migrated to FM is an 'average channel', containing 2 national, 1 semi-national and 3 local stations to be moved to FM (this excludes any stations already on FM). It is expected that FM would have sufficient space to accommodate this average channel.

The calculation flow of our model is illustrated in Figure 6.18 below.

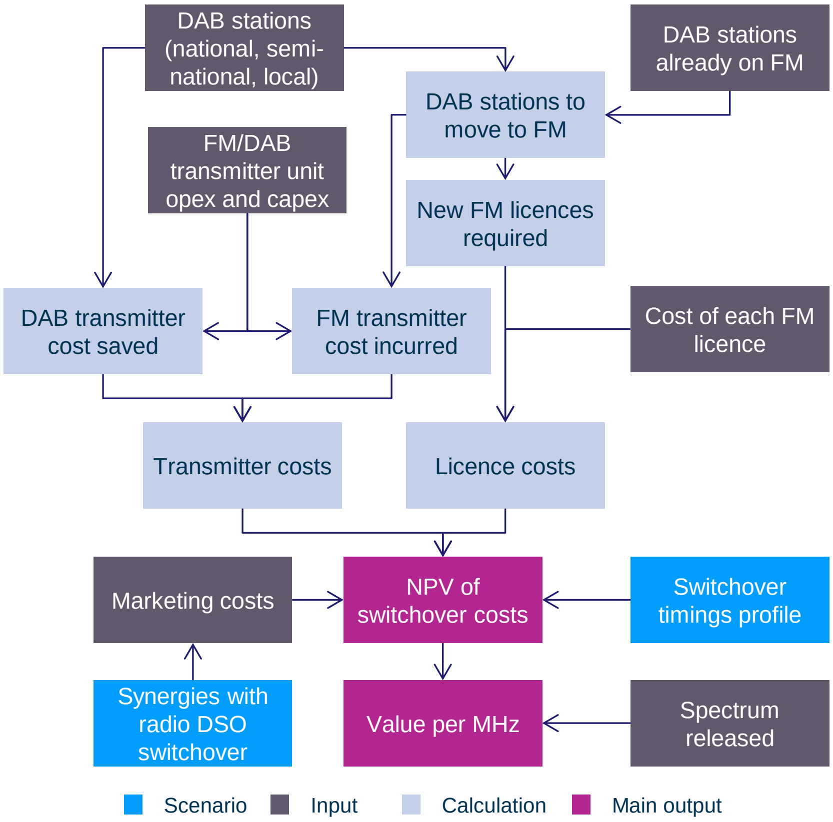


Figure 6.18: Flow diagram of the move of DAB stations onto the FM platform, LCA methodology [Source: Analysys Mason, 2012]

The results for FM are dependent upon the DSO scenario, as it is assumed that at DSO all non-local stations are transferred to DAB. There would therefore be a cost of having to migrate these stations back from FM to DAB. These results are shown in Figure 6.19 below.

We note that we have not included a requirement for additional FM licence fees in the costs in order to be consistent with not including the opportunity costs of the new band moved to in the calculation of the cost of moving for DTT, as discussed in Section 4.3.4.

Figure 6.19: Net present value breakdown into cost categories for LCA, for migration of a one DAB channel to the FM platform [Source: Analysys Mason, 2012]

NPV categories	*Counterfactual (GBP thousand per channel)*	*DSO Scenario 1 (GBP thousand)*	*DSO Scenario 2 (GBP thousand)*	*DSO Scenario 3 (GBP thousand)*
Costs of FM TX	22 956	40 596	20 086	20 183
Costs saved from DAB TX	-19 407	-17 026	-16 988	-16 995
Costs of re-planning	418	418	418	418
Costs associated with publicity	4980	4358	4358	4358
Total	**8948**	**28 347**	**7875**	**7964**
Spectrum released	1.5MHz	1.5MHz	1.5MHz	1.5MHz
Value/MHz/Annum	**427**	**1352**	**376**	**380**

DP approach

In considering the move to FM under the DP approach, we use an identical methodology to the LCA FM platform move model. As there are no radio receiver costs, the model does not consider optimising a radio receiver subsidy. However, the MUX operator does not necessarily need to migrate across each station from the DAB channel vacated but rather can choose to move only the most profitable stations.

It is assumed that a reduction of stations both reduces some of the infrastructure costs as well as reducing the total DAB listening hours, which in turn leads to reduced advertising income. The calculation of listening hours lost is based on the latest RAJAR listening figures, however we assume a proportion (50%) of the listening hours (and hence advertising revenues) will move to other stations rather than be lost from the platform entirely. The stations are removed in order of lowest listening hours per transmitter.

As with an optimisation of radio receiver subsidy we assume that the operator aims to minimise the combination of transmission costs and revenue loss. The calculation flow is illustrated in Figure 6.20 below.

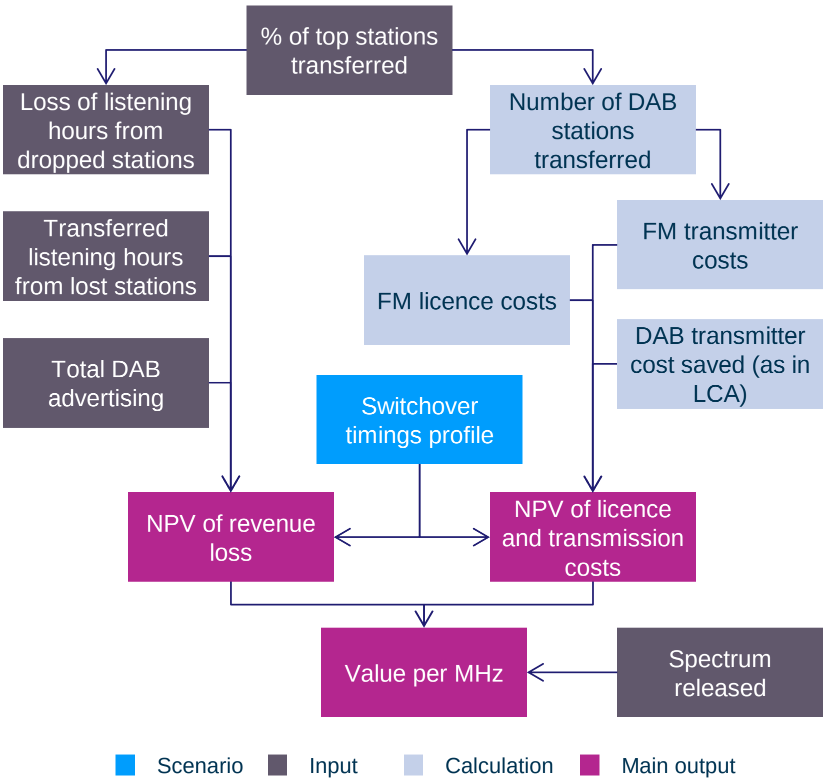


Figure 6.20: Flow diagram of the move of DAB stations onto the FM platform, DP methodology [Source: Analysys Mason, 2012]

The optimum level of stations to retain under the DP methodology is calculated at 95% for a move to FM under the counterfactual and DSO Scenario 1 and 100% under DSO Scenarios 2 and 3. A reduction to only 95% of the most popular stations relates to a loss in listening hours of 1% for DAB. This figure remains relatively stable against changing the assumption of the proportion of advertising from dropped stations that remains on the platform, i.e. transfers to another station.

The calculated costs are shown in Figure 6.21 below and are understandably very similar to those in the LCA case. Overall the move to FM represents the second least cost alternative, and second lowest cost under the DP approach, of all the different mitigation responses considered.

Figure 6.21: Net present value breakdown into cost categories for DP, for migration of a one DAB channel to the FM platform [Source: Analysys Mason, 2012]

NPV categories	Counterfactual (GBP thousand per channel)	DSO Scenario 1 (GBP thousand)	DSO Scenario 2 (GBP thousand)	DSO Scenario 3 (GBP thousand)
Costs of FM TX	19 733	35 190	20 086	20 183
Costs saved from DAB TX	-19 407	-17 026	-16 988	-16 995
Costs of re-planning	418	418	418	418
Costs associated with publicity	4731	4140	4358	4358
Loss from advertising	2280	3122	0	0
Total	**7756**	**25 845**	**7875**	**7964**
Spectrum released	1.5MHz	1.5MHz	1.5MHz	1.5MHz
Value/MHz/Annum	**370**	**1233**	**376**	**380**

6.4.4 Switch of DAB stations onto a new DRM+ platform

In addition to a migration to the alternative platform of FM, we have considered the possible response of migrating services to Digital Radio Mondiale (DRM). DRM is an alternative broadcasting system designed as a high-quality digital replacement for current analogue radio. DRM is designed to operate over either AM or FM bands, operating under the name of DRM30 or DRM+ in each band respectively.

DRM30 could operate in the UK either in the Medium Wave band (526–1606kHz) or at 26MHz. However BBC trials of DRM30 have found issues with Medium Wave interference problems at night, while 26MHz can be prone to international interference at periods of high solar activity. This combined with potential difficulties of international co-ordination in the MW, mean that we do not consider DRM30 to be a suitable replacement platform for DAB.

Rather we believe DRM+, which would operate in the current FM band, to be a more appropriate alternative to DAB. DRM+ should be able to re-use most of the physical infrastructure (masts, antennas) of the current FM network, with coverage and frequency planning being relatively simple. This however is only appropriate in situations where radio DSO have led to the FM network being turned off. Although it is assumed that the majority of equipment has not been immediately decommissioned and dismantled, but is instead available for the DRM+ network to use. This is consistent with the assumption made above when considering a move from DAB to FM in scenarios where DSO has occurred.

LCA approach

The cost of moving a single channel in the DAB platform to a different frequency, under the LCA approach, is determined by 5 key drivers:

- the costs of household radio set conversion from DAB to DRM+ (including a possibly loss from advertising in RR Scenario 1)
- the cost of new DRM+ transmission capex and opex requirements
- the costs of frequency re-planning to fully vacate the saved spectrum
- the costs associated with publicity of the technology upgrade
- the savings made from reducing future DAB transmission costs.

Unlike in the case of migrating to FM, DAB receivers are generally not compatible with DRM+ and therefore the costs of receiver conversion need to be considered. As no commercial DRM+ equipment yet exists on the market we have assumed a price of GBP80 per household set and GBP91 per car. This is the same relative costs between car and household receivers as was used for DAB+ radios.

Due to the large upfront costs of moving to DRM+ arising from radio receiver conversion, it makes sense to move multiple channels to DRM+ at the same time. As such, unlike in the case of FM, we model the cost for migrating all DAB channels to DRM+ rather than just a single channel. This mitigation strategy vacates 12MHz of spectrum (8 channels of 1.5MHz, as an additional channel is required to contain stations moved to DAB from FM following DSO).

As with DAB+, radio advertising revenue is assumed to be allocated on the basis of primary household radios and car radios. Therefore in RR Scenario 1 where only primary household radio receiver replacement is subsidised, an additional cost is included for any unsubsidised car radios which leave the service (calculated in the same way as in the DP case).

As was found with FM, due to the same lower frequency spectrum usage it is assumed for a roughly equivalent coverage DAB vs. DRM+ network, that 1.5x more transmitters and sites are required for coverage in DAB compared to DRM+. However in DRM+, each MUX has the capacity for only four stations – so the transmitters per station do not form as high a cost as was seen in FM, but are still higher than for DAB. The total change in transmission costs is calculated as the difference between the savings from eliminating DAB transmitter opex, and the reduced number of sites required for DRM+, and the capex and opex incurred for the new DRM+ transmitters. The calculation flow is illustrated in Figure 6.22 below.

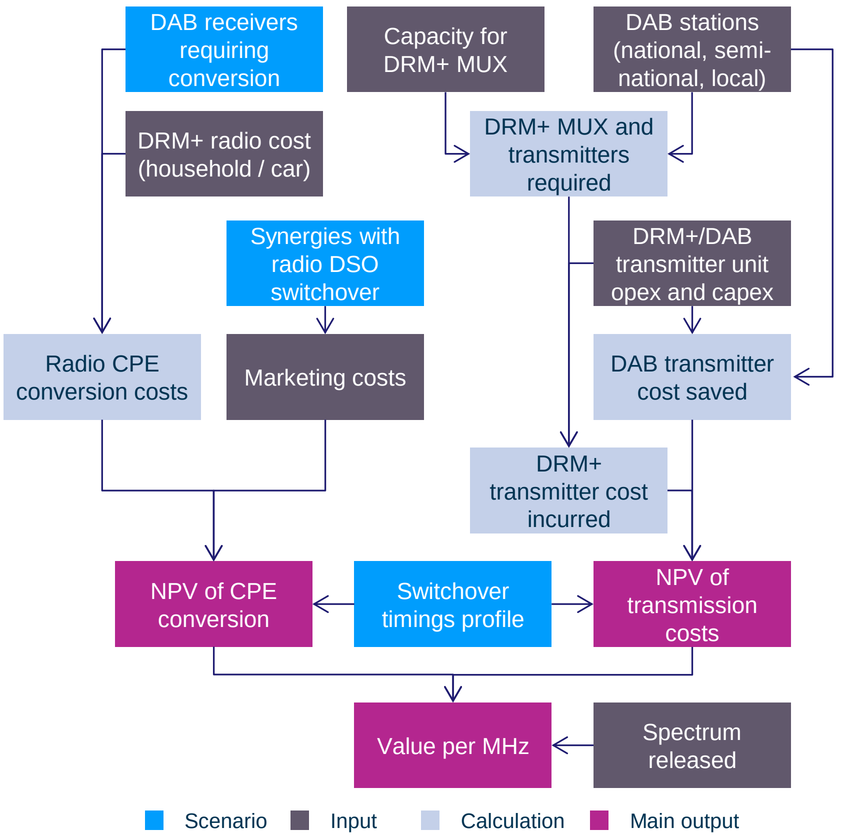


Figure 6.22: Flow diagram of the move of DAB stations onto a DRM+ platform, LCA methodology [Source: Analysys Mason, 2012]

We note that it is likely that while upgrading to DRM+ operators might wish to upgrade analogue studio-to-transmitter-links (STL) to digital and, as DRM+ can carry additional services, further link capacity might also be needed. However, we believe that under the minimum cost option there would be no problem using existing links that had fed the FM transmitter, and so these additional costs are not included in our LCA analysis.

The results of the LCA calculation for the applicable DSO scenarios (i.e. where DSO has already occurred) are shown in Figure 6.23 below. The requirement for new radio receivers for all listeners and for a new platform mean that this is the most expensive of all options considered and therefore does not come close to forming the LCA.

Figure 6.23: LCA cost for a move to a DRM+ platform [Source: Analysys Mason, 2012]

Mitigation strategy	*Counterfactual (GBP thousand/ MHz/annum)*	*DSO Scenario 1 (GBP thousand/ MHz/annum)*	*DSO Scenario 2 (GBP thousand/ MHz/annum)*	*DSO Scenario 3 (GBP thousand/ MHz/annum)*
RR Scenario 1	N/A	13 687	N/A	9461
RR Scenario 2	N/A	27 487	N/A	14 881
RR Scenario 3	N/A	30 181	N/A	17 067

A further breakdown of the cost drivers for RR Scenario2 is shown below in Figure 6.24.

Figure 6.24: Net present value breakdown into cost categories for LCA, RR Scenario 2, for a move to a DRM+ platform [Source: Analysys Mason, 2012]

NPV categories	DSO Scenario 1 (GBP thousand)	DSO Scenario 3 (GBP thousand)
Cost of replacement receivers	4 636 138	2 560 660
Costs of DRM+ transmission capex	1580	708
Costs of DRM+ transmission opex	72 670	34 817
Costs of re-planning	418	418
Loss (/savings) from DAB transmission	-136 207	-135 960
Loss from reduced users[102]	0	0
Costs associated with publicity	34 863	34 863
Total	**4 609 463**	**2 495 506**
Spectrum released	12.0MHz	12.0MHz
Value/MHz/Annum	**27 487**	**14 881**

DP approach

As with other mitigation options, we apply a similar methodology for calculating the costs for changing from using DAB to DRM+ under the DP approach as for under the LCA approach. However, in the migration to the DRM+ DP case, we consider the savings that can be made from the operator both not moving every DAB station across to the new platform and the operator not fully subsidising the radio receiver costs of conversion for DRM+.

We implement these two optimisation processes in stages, with the DRM+ revenues left following any loss of revenue due to a reduced number of stations, then being used as the total revenues for scaling due to any reduction in listeners.[103]

Initially the number of stations transferred is optimised as under the FM DP case, where this is calculated by minimising the costs of transmission and the loss of revenue from reduced listening hours for different levels of stations being transferred. Due to the reduced costs of carrying stations on DRM+ over FM, it is calculated that every station should be transferred to the new platform.

Subsequently the amount of radio receiver subsidy given to each user is optimised as under the DAB+ DP case. This is calculated by minimising the costs of any subsidy and the loss of revenue from a reduced number of listeners. The number of users not transferring to DRM+ is calculated

102 Loss from advertising only occurs in RR Scenario 1, where the subsidy doesn't fully cover car radio equipment so some people leave the platform rather than migrating to DRM+.

103 We note that the specific order of these optimisations could theoretically make a difference under certain sets of assumptions. However we have tested modelling the two stages in either order and can confirm that our results remain unaffected using the modelled parameters. In a situation where this order did make a difference, we believe that the chosen order of optimisation is sensible given that commercial decisions for a radio station to leave DAB are likely to be made significantly in advance of any consumer decision to leave the platform.

using the WTP (assumed to be the same as for DAB) and the costs of DRM+ conversion to the user (i.e. equipment costs less the subsidy amount). It is found under DRM+ that no subsidy should be given for the new receivers, as was the case for DAB+, which results in a loss of 22-26% of listeners relative to the DAB platform.

The calculation flow is illustrated in Figure 6.25 below.

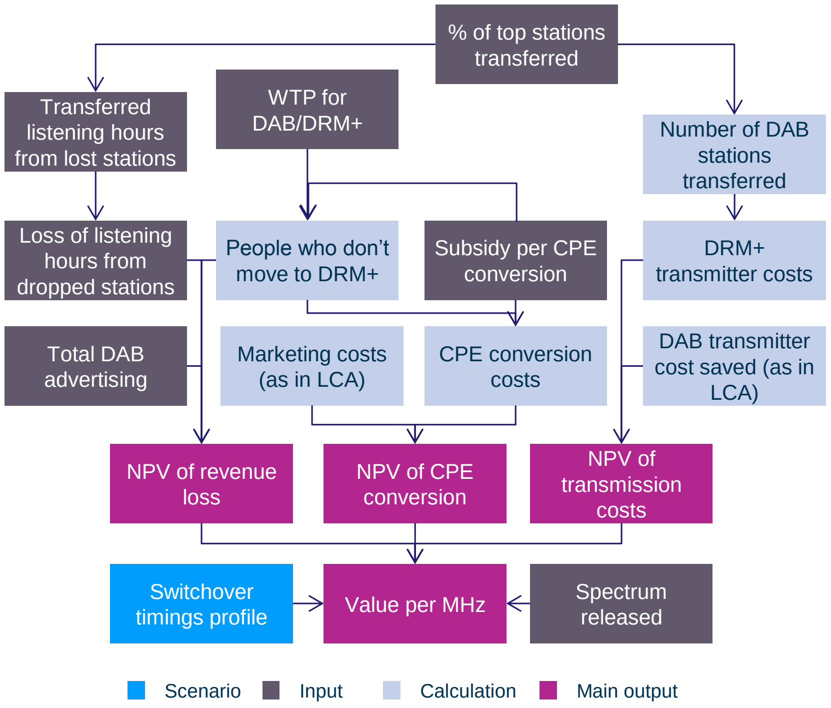


Figure 6.25: Flow diagram of the move of DAB stations onto a DRM+ platform, DP methodology [Source: Analysys Mason, 2012]

As mentioned above, we do not consider the possibility of a move to DRM+ under either the Counterfactual or DSO Scenario 2, because the FM platform would still be in operation at the time of the spectrum loss and therefore the necessary spectrum for DRM+ would not available for the move. The results of the DP calculations are shown in Figure 6.26 below. Whilst not at the same level as the LCA costs, this option still results in a high cost even under the DP methodology.

Figure 6.26: Net present value breakdown into cost categories for DP, RR Scenario 2, for a move to a DRM+ platform [Source: Analysys Mason, 2012]

NPV categories	DSO Scenario 1 (GBP thousand)	DSO Scenario 3 (GBP thousand)
Cost of replacement receivers	0	0
Costs of DRM+ transmission capex	1076	495
Costs of DRM+ transmission opex	48 986	23 646
Costs of re-planning	418	418
Loss (/savings) from DAB transmission	-136 207	-135 960
Costs associated with publicity	34 863	34 863
Loss from reduced users	1 648 750	1 233 686
Total	**1 597 886**	**1 157 148**
Spectrum released	12.0MHz	12.0MHz
Value/MHz/Annum	**9528**	**6900**

Overall the costs of transferring to DRM+ are higher in all DSO scenarios (and for both DP and LCA) than transferring to FM. This is due to the high levels of radio receiver replacement costs (and high levels of lost revenue from listeners in the DRM+ DP case) which more than compensates for DRM+'s lower transmission costs than FM.

6.5 Summary of opportunity costs for DAB spectrum in own use

Overall, spectrum scarcity was not found in either of the DAB spectrum bands. If there was excess demand for DAB spectrum in own use and alternative use and Ofcom chose to charge AIP, the AIP levels would need to depend both on the own use opportunity costs, discussed below, and the alternative use opportunity costs, discussed in Section 7.

We do not consider the opportunity cost of inter-leaved usage of the spectrum due to the exclusive usage of the spectrum by DAB multiplexes running SFNs, and the minimal usage of PMSE and PBR within the used DAB bands.

We have analysed the costs of our different potential responses to mitigate a loss of DAB spectrum using both the LCA and DP approaches. The results are summarised in Figure 6.27.

Figure 6.27: Mitigation costs across DAB spectrum loss responses under both LCA and DP cases (for RR Scenario 2: replacement of primary household and car radios) [Source: Analysys Mason, 2012]

Mitigation strategy	Counterfactual (GBP thousand/ MHz/annum)	DSO Scenario 1 (GBP thousand/ MHz/annum)	DSO Scenario 2 (GBP thousand/ MHz/annum)	DSO Scenario 3 (GBP thousand/ MHz/annum)
LCA: Upgrade of MUXs to DAB+	9306	18 227	7876	9208
DP: Upgrade of MUXs to DAB+	1794	3603	2069	2407
LCA: Moving 1 channel to anew frequency	**98**	**101**	**95**	**96**
DP: Moving 1 channel to anew frequency	**98**	**101**	**95**	**96**
LCA: Switching 1 channel's stations onto FM	427	1352	376	380
DP: Switching 1 channel's stations onto FM	370	1233	376	380
LCA: Switching all stations onto DRM+	N/A	27 487	N/A	14 881
DP: Switching all stations onto DRM+	N/A	9528	N/A	6900

Note: Values in red represent the lowest-cost response for each approach

The lowest cost (shown in red in Figure 6.27), under all of the radio DSO scenarios, arises from the move of one or more channels' content to a different frequency within VHF Band III. We note that the move to a different spectrum channel considers a move to Channel 11A and other empty channels currently reserved for DAB in the first instance. However, this cost would remain constant for migration to any channel within VHF Band III. In practice though, Ofcom may wish to consider the difficulties of clearing spectrum outside of the current DAB reserved spectrum, including any difficulties from international coordination.

The costs for switching to DRM+ and upgrading to DAB+ are both significantly higher than for moving a channel's contents to a new frequency because they require the provision of new radio receivers for the majority of listeners (all listeners in the case of DRM+), which is very costly. For switching to FM there is a cost for new transmitters, whilst for changing the channel being used only a lower cost new combiner is required.

7 Opportunity cost in alternative use for DAB spectrum

This section discusses the opportunity cost calculations for the DAB spectrum in alternative use. The remainder of the section is set out as shown in Figure 7.1 below.

Figure 7.1: Map of Section 7 [Source: Analysys Mason, 2012]

7.1 Introduction

The frequency blocks considered could potentially be used for a range of alternative services rather than the current DAB usage; those of most significance are detailed in Figure 7.2 below.

Figure 7.2: Summary of potential alternative uses for DAB spectrum bands [Source: Analysys Mason, 2012]

Band/Sub-band	*Possible alternative uses*
174.160–175.696MHz (currently DAB)	PMSE, PBR
210.880–229.840MHz (currently DAB)	PMSE, PBR, fixed links (also used for maritime mobile in parts of ITU Region 2)

While there are some existing PMSE services using DAB spectrum, this is not as a result of using interleaved spectrum as discussed for PMSE users of DTT spectrum in Section 4.5. PMSE makes use of the spectrum not currently used by DAB (but still within the ranges in the table above which is referred to throughout this document as ‘DAB spectrum’).

While DTT and local TV have been considered, we do not believe that they are credible alternative uses for the DAB spectrum due to their requirement for multiple contiguous DAB blocks to be released. For example, six blocks of 1.5MHz of DAB spectrum would be required to provide one DTT channel of 8MHz. Furthermore, the costs to DTT and local TV providers of investing in the necessary equipment in order to make use of this spectrum is likely to be at a level such that there is zero demand from these services. Furthermore, access to a channel in this range would certainly not decrease the costs to DTT or local TV operators of providing their existing levels of output. This is all that should be considered under the LCA approach.

Other alternative uses, such as PBR or PMSE, remain credible as it is feasible that one DAB block could provide sufficient spectrum for alternative use.

As for the DTT spectrum, alternative use calculations are only calculated via an LCA methodology.

7.2 Opportunity cost of PMSE use

The conclusion of no excess demand made in Section 6.2 results in an opportunity cost of zero as discussed for PMSE alternative use for DTT spectrum in Section 5.2. Thus, dedicated access to the band would not be a viable alternative use in terms of the opportunity cost.

We note once again however that there is a risk that PMSE could become increasingly squeezed as the supply of suitable spectrum decreases following 800MHz allocation to mobile and the potential allocation 700MHz to mobile in the future. If this were to be the case then conclusions on excess demand for PMSE services may need to be re-evaluated.

7.3 Opportunity costs of other alternative uses

PBR

As can be seen in Section 6.2, there is no excess demand for PBR services in these spectrum bands and PBR service providers wishing to provide services within Band III are likely to have plenty of spectrum available for use without requiring the freeing up of a DAB band. There will therefore be zero cost savings to service providers and hence a zero opportunity cost.

Fixed links

Section 6.2indicates that there is no excess demand for fixed links within the DAB spectrum bands and as such we would expect the opportunity cost of the DAB spectrum to fixed terrestrial link service users to be zero.

7.4 Summary of opportunity costs for DAB spectrum in alternative uses

As a result of our analysis, we do not consider that there are any alternative uses of DAB spectrum which have a higher opportunity cost of using the spectrum than that for DAB own use.

8 Conclusions

In this study, we have calculated the opportunity costs associated with the spectrum currently used for DTT and DAB. Our aim was to produce a quantitative assessment that could be used as an input to a potential calculation of AIP fees by Ofcom, should it choose to apply AIP to these spectrum bands.

In general, our opportunity cost calculations in own use have been designed to provide cost estimates for different approaches to mitigating a loss of spectrum. With some of these options there may be significant practical difficulties, which we have sought to highlight to Ofcom, and which are discussed further in Section 8.2 below.

Ofcom may conclude that in some cases these practical difficulties are insurmountable or that the option is otherwise not viable in practice. If Ofcom were to decide that an option was impractical, we suggest that the next lowest-cost alternative (or next lowest DP-based opportunity cost) should be taken forward as the relevant opportunity cost of the spectrum.

We have split the DTT band into three sub-bands; Channels 21–30, 39–48 and 49–60. Similarly, we have split DAB into two sub-bands; used (Channels 11B to 12D) and unused (Channels 10B to 11A).

For each sub-band we have drawn conclusions based on:

- scarcity/excess demand
- opportunity costs in own use and in alternative use.

This section will summarise our main findings from both of these stages.

8.1 Assessing scarcity/excess demand

We have investigated the level of expected excess demand in 2015 for both DTT and DAB spectrum. From our analysis we conclude that spectrum scarcity is likely to exist for the primary use of the DTT spectrum bands. However, we do not believe that spectrum scarcity is likely to exist for either the DAB spectrum or in secondary interleaved use of the DTT spectrum. This secondary interleaved use consists of both high-power, long-range services (such as local TV) and low-power, local uses (such as PMSE).[104]

Our DTT and PMSE scarcity assessment is consistent with previous findings from the Indepen/Aegis AIP work and Analysys Mason’s 2009 PMSE report respectively. However, our conclusions on DAB differ from the Indepen/Aegis report as the actual development of the market following their report has been considerably slower that the predictions at the time, with FM

104 Whilst local TV services may impose some extra constraint on PMSE services, we do not consider the spectrum available for PMSE to be scarce.

remaining the key platform in terms of both radio listening time and advertising revenue. We also note that the Indepen/Aegis' predicted take off of DVB-H has not occurred and as such does not add to the demand for the spectrum.

While this document is not intended to comment on whether the overall application of AIP to broadcasting is appropriate, our findings as regards scarcity would imply that, if AIP were to be charged, it should only be considered for application to national DTT services, and not to local TV services, to DAB or to PMSE in the bands considered.

8.2 Determining opportunity costs in own use and alternative use

For the three DTT sub-bands and the two DAB sub-bands, we have assessed the lowest costs of spectrum loss mitigation under both the LCA and DP approaches. The results are summarised in Figure 8.1 below. In all cases the costs are normalised on a per MHz per annum basis. The values shown represent the first year's opportunity costs in a series of per annum opportunity costs calculated so as to be flat in real terms into perpetuity. Where spectrum is not considered scarce we have applied the same methodologies to calculate values to current users. These values would represent the opportunity costs were the spectrum to be considered scarce.

Figure 8.1: Results of calculation of the opportunity costs of the DTT and DAB spectrum [Source: Analysys Mason, 2012]

Mitigation strategy	Excess demand	Own use LCA (GBP thousand /MHz/annum)	Own use DP (GBP thousand /MHz/annum)	Alternative use LCA (GBP thousand/ MHz/annum)
DAB Channels 11B to 12D	None	95–101[105]	95–101	0
DAB other	None	0	0	0
DTT Channels 21 to 30	In own use	74	74	0
DTT Channels 39 to 48	In own use	321	270	0
DTT Channels 49 to 60	In own and alternative use	413	353	1580
DTT interleaved local TV spectrum	None	51.2	2.2	0
PMSE	None	1.8	1.8	0

For DAB, the values are between GBP95 000 and GBP101 000 per MHz per annum depending on the DSO scenario considered. These values are relatively low, in addition to the spectrum not being scarce, which may imply a zero opportunity cost. However, we do note that, should migration to other channels within VHF Band III or to the FM platform be considered impossible, the value of the spectrum in own use would be considerably higher.

105 Dependent upon radio DSO scenario

We observe that the values for interleaved use of the DTT spectrum for PMSE and local TV are very low, particularly under the DP approach.

For national DTT the opportunity costs vary across the different DTT sub-bands. For Channels 21-30 the opportunity cost is relatively low at only GBP74 000 per MHz per annum. This is because it is possible (hypothetically) to migrate channels from this sub-band to the 600MHz band without having to replace any receiving aerials. In the other DTT sub-bands the opportunity costs are higher as a migration to the 600MHz band is not quite as straightforward, even if it remains the option with the lowest opportunity cost in most cases.

In the 700MHz band (Channels 49 to 60) however, there is also a substantial opportunity cost in alternative use (mobile) which is significantly higher than the opportunity cost in own use. We note that this is due to the economies of scale gained through the use of bands which are internationally harmonised for mobile services. Therefore the 700MHz band offers significant value to mobile users in a way which the 600MHz band, and other lower frequency DTT spectrum, do not.

Ofcom may decide that the practical considerations may make some of our considered spectrum loss mitigation strategies impracticable. These practical considerations are summarised in Figure 8.2 below. In such cases the opportunity cost may need to be increased to reflect the next lowest-cost spectrum loss mitigation strategy.

We also note that as spectrum loss mitigation strategies are implemented over time, either to vacate spectrum (such as a move into the 600MHz band to clear the 700MHz band) or deal with increased demand (such as the gradual move to DVB-T2) these options may no longer be available. However, other mitigation strategies may arise such as upgrading to other more efficient technologies.

Figure 8.2: Practical considerations relating to different alternative responses [Source: Analysys Mason, 2012]

Channels to be vacated	Spectrum-loss mitigation strategy	Practical consideration of mitigation strategy
DAB Channels 11B to 12D	LCA + DP: Moving 1 or more channels to a new frequency	Moving the channel to outside the current DAB band could trigger issues of international coordination, and the need to move existing spectrum users Moving the channel within Channels 10B to 11A would makes sense for calculating opportunity costs, but note that this approach could not be followed for moving all channels in the band.
DAB other	None	None
DTT Channels 21 to 30and DTT Channels 39 to 48	LCA + DP: Move of up to 7 channels to use the 600MHz band	In each case this alternative only considers the cost of moving up to 7 channels which would be below the actual cost of mitigating a loss of the entire band. We do not anticipate particular difficulties in international coordination of the 600MHz band[106] though Ofcom should have more detailed data on this point.
DTT Channels 49 to 60	LCA: Upgrade of MUXs to DVB-T2	Any transmitters operating in the Channels 49 to 60 range (which do not only form part of the MUXs to be removed) would need to move into the lower frequencies and as such international coordination would be required. While customers may be annoyed at having to replace their relatively new post-DSO equipment so quickly (even though this could be operator funded), most should be amenable given the advantages of receiving the HD channels.
DTT Channels 49 to 60	DP: Move of 7 channels to use the 600MHz band	As above, but the alternative use in this case (mobile) would require access to the whole sub-band; a move of 7 channels is therefore unlikely to be sufficient. As no more than 7 channels can be moved to the 600MHz band either a move to a lower frequency band or some upgrading to DVB-T2 would need to be considered. We understand that Ofcom has considered these issues further as part of the UHF strategy statement.
DTT interleaved local TV spectrum	LCA + DP: Move to alternate frequency channel	Where possible the 600MHz band has been used for the move, and the issues would be identical to those above. In addition we note that a radio planning exercise would need to be run to check that the aerial groups that don't cover the 600MHz band can find alternative frequencies 'in group'.

106 The Arqiva report '700 MHz Clearance Planning Options Based on Existing Usage', highlighted special difficulties with finding new channels for Dover, Whitehawk Hill and Midhurst when vacating the 700MHz band, but no particular difficulties with coordination of the 600MHz band where mentioned.

Annex A Glossary

Term/Abbreviation	*Meaning*
600MHz band	The eight channels between 550–614MHz (UHF Channels 31 to 38). These are currently empty following analogue TV switch-off.
700MHz band	The twelve channels between 694–790MHz (UHF channels 49 to 60). These are subject to a provisional decision at WRC-12 to allow for a co-primary mobile allocation in the 700MHz band within ITU Region 1
AIP	Administrative Incentive Pricing. An annual spectrum fee to be paid, usually valued beyond the cost of spectrum management
Alternative use	Any potential use of spectrum other than the current use
Band	A band (or sub-band) is a collection of normally contiguous frequency channels, which are generally allocated for the same purpose.
CBA	Cost–benefit analysis.
Channel	The term channel has been used throughout this document to refer to a small block of frequency which can be used by either DAB or DTT, and over which a single MUX can be broadcast. A channel in the context of DAB has a width of 1.5MHz, whilst a channel in the context of DTT is 8MHz wide
COFDM	Coded orthogonal frequency division multiplexing
COM	Commercial broadcasting. Where the primary aim of the broadcaster is to provide a profitable return on investment for their shareholders. This includes all non-PSB broadcasters.
CPE replacement scenario	Customer premise equipment replacement/conversion scenario. Within this document we consider the following scenarios for DTT modelling: • CPE replacement scenario 1: Replacements only for the primary DTT-only TV set in any household • CPE replacement scenario 2: Replacements for any primary or secondary DTT-only TV set in any household • CPE replacement scenario 3: Replacements for any DTT-only TV set in any household • CPE replacement scenario 4: Replacements for every DTT-only TV and any TV that has an integrated DTT receiver (whether this set is only used for DTT or not).
DAB	Digital audio broadcasting. A digital alternative to analogue radio. DAB currently only uses the frequencies 218–230MHz, though we have considered the larger DAB reserved range of 211–230MHz plus Block 5A (174–176MHz) in this document.
DP	Discounted profit. An approach to calculating the opportunity cost of mitigating a loss of spectrum where the service level can be reduced to create the most profitable business plan given the new spectrum level.
DRM	Digital radio mondiale. An alternative broadcasting system designed as a high-quality digital replacement for current analogue radio. DRM is designed to operate over either AM or FM bands, operating under the names of DRM30 or DRM+ in each band respectively.
DSO	Digital switchover. The nationwide switch from analogue to digital services. TV DSO began in 2008 and finished in 2012. Radio DSO has been considered, but a decision on whether to go ahead or details on when this might take place have not been issued. Within this document we consider the following radio DSO scenarios:

	• Counterfactual – No digital switchover • DSO scenario 1 – UK-wide switchover in 2015 • DSO scenario 2 – UK-wide switchover in 2018 following market trends (i.e. at a time when DAB is assumed to have reached similar coverage and listenership to FM) • DSO scenario 3 – Phased nation-by-nation switchover (England switches in 2017, Wales in 2018 and Scotland and Northern Ireland in 2019)
DTH	Direct-to-the-home
DTT	Digital terrestrial television. Frequently referred to as Freeview though this may also include some pay services such as Top Up TV, and forms part of the YouView service. DTT uses frequencies in the ranges 470–550MHz and 614–790MHz.
DVB-H	Digital Video Broadcasting for mobile handheld services. A broadcast technology optimised for small screen mobile devices intended to reduce the need to transmit multiple videos streams to subscribers.
DVB-T/DVB-T2	Digital Video Broadcasting first (T) and second (T2) generation terrestrial services. The set of standards relating to DTT transmissions within the UK. DVB-T transmits at a lower data rate than DVB-T2, and in the UK DVB-T2 is currently only used to transmit HD stations (though it could in principle also be used for SD services)
Gateway	ADVB-T2 gateway sits at the top of the headend, where it receives one or more multiplexes which are encapsulated into data frames to be sent to the DVB T2 modulators via leased lines or satellite.
HD	High definition
Headend	A (video) headend is a network site/facility where TV content is aggregated and processed ready for distribution over the DTT network towards the transmitters.
HetNet	Heterogeneous network. A mobile network using a diverse set of base-station types (such as pico-, micro- and macro-cells) in order to both eliminate coverage holes and improve capacity.
HSPA, HSPA+	High-speed packet access
ID-TV	Integrated digital TV
LCA	Least cost alternative. In ‘own use’ this is the opportunity cost required to fully mitigate a loss of spectrum while retaining the same level of output from the current spectrum users. In ‘alternative use’ this is the opportunity gain from an alternative user from gaining an additional amount of spectrum, but again while retaining the current level of output
LRIC	Long-run incremental cost
LTE	Long-Term Evolution (of mobile telecommunications standards)
MBB	Mobile broadband
MFN	Multi-frequency network. Where adjacent sites in a network broadcast the same information using different frequencies. DTT in the UK uses this technique.
Modulator	A modulator converts the signal from the DTT gateway into COFDM modulated form ready for transmitting at each individual site.
MPEG-n	‘Moving picture experts group’ family of standards for video imaging
MUX	Multiplex. The encoding and blending together of multiple digital TV/radio stations into a single transmission. This multiplex is broadcast across a single channel and then decoded and split into multiple stations again by the receiver,
NPV	Net present value
Own use	The permitted use under the current allocation of the spectrum

PBR	Private business radio
Petalling	Petalling is a technique by which different MUX signals are transmitted in different directions (similar to sectorisation on mobile sites) enabling specific local TV channels to be targeted at specific geographic areas which will be interested in their content.
PMR	Professional mobile radio or "private mobile radio",
PMSE	Programme-making and special events
PSB	Public service broadcasting. The public service broadcasters have public service obligations under the terms of their licences and these include having to provide higher levels of national coverage than commercial broadcasters. In this document, the term PSB is used to refer to the BBC, ITV, Channel 4 and Channel 5.
RR scenario	Radio replacement/conversion scenario. These are the DAB parallel of our CPE replacement scenarios for DTT. Within this document we consider the following scenarios for DAB modelling: • RR scenario 1: Just primary household DAB radios • RR scenario 2: Primary household DAB radios and all DAB car radios (we consider this to be the most likely scenario) • RR scenario 3: All household DAB radios and all DAB car radios
Scarcity (or excess demand)	Where more demand exists for use of a particular block or band of spectrum than there is supply (i.e. bandwidth available to fulfil this demand)
SD	Standard definition
SFN	Single frequency network. Where all sites in a network broadcast the same information using the same frequency. DAB in the UK uses this technique, and it is used by DTT in some other countries around Europe
Station	The term 'station' is used in this document to refer to a continuous stream of TV or radio programming (such as BBC1, or Radio1) issued by a broadcaster, and encoded along with multiple other stations on a single MUX to be transmitted
SFN	Single-frequency network
STB	Set-top box. This is a device which sits between an aerial and a TV set and decodes the DTT signal received
TD-LTE	Time division LTE. LTE network deployed using time division duplexing
TDD	Time division duplex. Duplexing system that uses a single frequency to transmit signals in both the downstream and upstream directions as a result of the allocation of different time slots within the frequency band
TD Bands	Time division duplex bands. The bands of spectrum used, or to be used, for TDD services
TX	Transmitters used for DAB or DTT
WACC	Weighted average cost of capital
WTP	Willingness to pay
WRC-n	World Radiocommunication Conference

Annex B DTT aerial replacement calculations

B.1 Overview of aerial replacement

Three of the four responses considered to mitigate a loss of DTT spectrum in own-use may require some proportion of household aerial receivers to be replaced. These responses are: the migration to using the 600MHz band; the upgrade to using DVB-T2; and the option of using an SFN in Channel 36 (which also requires a DVB-T2 upgrade). In this Annex we provide more detail on the calculation of the number of receiving aerials which would need replacement for each of these responses and in the event of losing spectrum from each of the three DTT sub-bands we have identified.

In each case, to calculate the number of aerials that would need replacing, we first calculate the number of households that are affected. We then calculate the proportion of these households' aerials that would go out-of-group under each proposed re-plan, as detailed in Sections B.3 onwards. To do this, we use the aerial grouping definitions shown in Figure B.1 below.

Aerial group	*Channels*	*Frequencies*
A	21–37	470– 599MHz
B	35–53	583– 727MHz
C/D	48–68	687– 847MHz
E	35–68	583– 847MHz
W	21–68	470– 857MHz

Figure B.1: Aerial grouping by channel and frequency [Source: Analysys Mason, 2012]

However, even when used out of band, a proportion of aerials will still work, especially when used in close proximity to higher-powered transmitter sites. To take account of this, we have modelled the proportion of aerials which are close enough to a transmitter to still receive an acceptable signal even after out-of-band attenuation is accounted for.

This modelling was done in MapInfo using the geocoded site location of each transmitter site, overlaid on a map of UK postcodes (excluding Northern Ireland), including the number of residential households per postcode, as shown in Figure B.2 below.

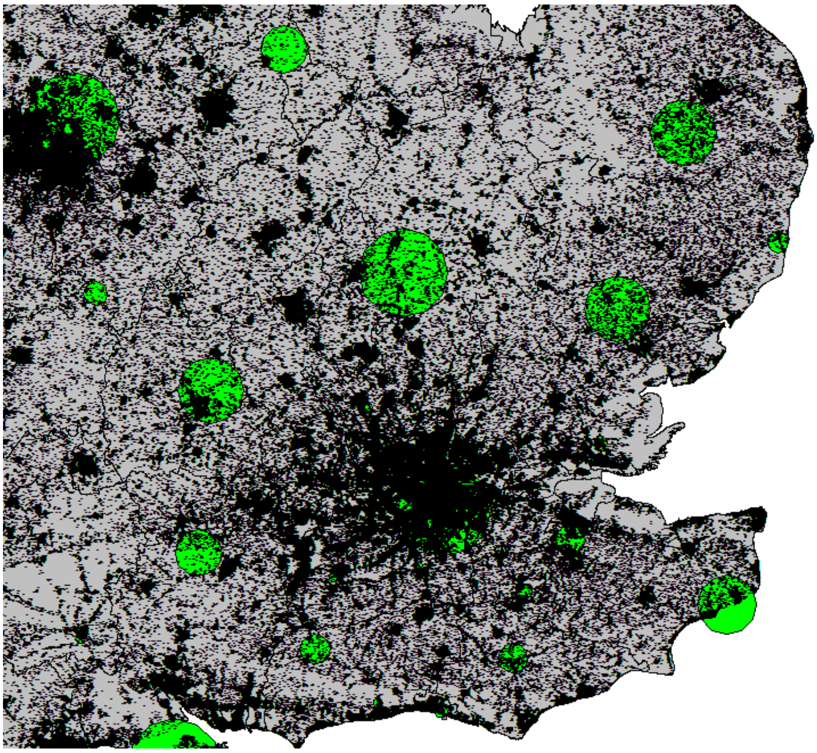


Figure B.2: Example of transmitter out-of-group aerial mapping. Green circles represent the theoretical radius of antennas after a 19dB drop-off [Source: Analysys Mason, 2012]

The proportion of aerials that do not require replacing was assumed to be the number of households covered by a theoretical out-of-band transmitter radius, divided by the total number of households in the full coverage area of the transmitter (i.e. receiving their DTT signal from that site). This out-of-group radius was defined as the radius at which the power of a signal received at a STB (i.e. after aerial attenuation[107]) at the edge of the cell, by an out-of-group aerial, would be the same as the power of a signal received by an in-group aerial at the edge of a normal transmitter's radius.

To simplify the calculation of the out-of-group transmitter radius, we assumed an average drop of 19dB across an out-of-group aerial. This value was chosen as it is the maximum, across each group type of aerials, of the average out-of-band attenuations calculated from the Ofcom data for grouped aerial attenuation, shown in Figure B.3 below. It is assumed that the new channels chosen in any re-planning exercise could be designed so that even the furthest out-of-band channel chosen would remain within this 19dB drop-off, meaning that our 19dB attenuation is likely to be conservatively high.

107 The aerial attenuation is the drop in signal strength between that received at the aerial and that passed through to the STB or other CPE. The better aligned the aerial's 'group' (i.e. channels it is designed to be compatible with) to the channel on which the signal is received, the smaller the drop in signal strength will be.

Channel number	Group A (dB)	Group B (dB)	Group C/D (dB)	Group E (dB)
21	**0**	19	16	14
22	**0**	17	18	12
23	**0**	15	20	10
24	**0**	13	22	8
25	**0**	11	24	7
26	**0**	9	25	6
27	**0**	7	26	5
28	**0**	5	28	4
29	**0**	4	29	3
30	**0**	3	30	2
31	**0**	3	25	2
32	**0**	3	20	2
33	**0**	3	15	2
34	**0**	3	12	2
35	**0**	**3**	9	**2**
36	**0**	**2**	6	**2**
37	**2**	**2**	4	**2**
38	8	**1**	3	**1**
39	15	**0**	2	**1**
40	16	**0**	2	**0**
41	17	**0**	2	**0**
42	18	**0**	2	**0**
43	19	**0**	2	**0**
44	20	**0**	2	**0**
45	21	**0**	1	**0**
46	22	**0**	1	**0**
47	23	**0**	1	**0**
48	23	**0**	**1**	**0**
49	23	**0**	**0**	**0**
50	22	**0**	**0**	**0**
51	22	**0**	**0**	**0**
52	21	**0**	**0**	**0**
53	21	**0**	**0**	**0**
54	20	1	**0**	**0**
55	19	2	**0**	**0**
56	19	4	**0**	**0**
57	19	6	**0**	**0**
58	19	8	**0**	**0**

Figure B.3: Attenuation of grouped aerials receiving signals at different channels (bold indicates designated in-group channels) [Source: Ofcom, 2011][108]

108 See http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/awards-in-preparation/2011/600mhz/600MHz-Band-Study.pdf

Channel number	Group A (dB)	Group B (dB)	Group C/D (dB)	Group E (dB)
59	19	10	**0**	**0**
60	19	16	**0**	**0**
61	19	17	**0**	**0**
62	19	18	**0**	**0**
63	19	18	**0**	**0**
64	19	19	**0**	**0**
65	19	20	**0**	**0**
66	19	20	**0**	**0**
67	19	21	**0**	**0**
68	19	22	**0**	**0**

To calculate the theoretical current in-band radius of each site we used the effective radiated power (ERP) of the largest MUX transmitter on each site, calibrating the radius of a 10 000kW transmitter to the Ofcom DTT link budget calculation.[109] Using this, the radius is calculated at which a signal is as strong using the 19dB attenuating aerial as is found at the edge of the current radius using a 0dB aerial attention. This radius is plotted around each transmitter, and the number of households that fall within this area is calculated based on UK census data.

For both of these calculations an inverse power law is used. We note that this most likely slightly overestimates the radius for higher-power transmitters, and slightly underestimates it for the smaller infill sites. However, this effect should be balanced by our assumption of a high out-of-band attenuation.

In sections B.3 to B.5 we will describe the calculation of the proportion of receiving aerials which would require replacement for the three responses to a loss of spectrum. However, we first consider the proportions of households affected by each of the responses.

B.2 Households affected

For the move to an SFN, we consider all households receiving a COM signal to be affected. However, for the move to DVB-T2 or the move of seven channels to alternative frequencies, a more complicated calculation is needed in order to consider the likelihood of a household being affected given the vacation of either 10 or 7 channels within each sub-band. This depends on both the natural grouping of the six MUXs received by households, the distribution of transmitters operating in each sub-band, and the main aerial types used within each sub-band.

In the case of vacating Channels 21 to 30, it is assumed that any household that receives one frequency channel in this group will also have the other five channels in this group. This is

109 See: http://stakeholders.ofcom.org.uk/binaries/consultations/clearedaward/transfinite.pdf

because aerial Group A does not reach outside of this sub-band. As such, the number of households in this group can be approximated as the number of transmitters operating in the Channel 21 to 30 sub-band, over the total number of transmitters. This gives the proportion of the total UK households affected as around 38%, as shown in Figure B.4.

	Channels 21 to 30	Channels 39 to 48	Channels 49 to 60
Number of PSB transmitters (>5kW)	73	38	47
Number of COM transmitters (>5kW)	42	51	54
Which relates to			
Proportion of PSB transmitters	46%	24%	30%
Proportion of COM transmitters	29%	35%	37%
Proportion of transmitters weighted by PSB/COM coverage areas	**38%**	**29%**	**33%**

Figure B.4: Calculation of the weighted split of transmitters, to use as an approximation of households affected assuming all channels are grouped into sub-bands [Source: Analysys Mason, 2012]

In the case of vacating Channels 39 to 48 and Channels 49 to 60, it is assumed that each sub-band is split evenly between the aerial groups it contains (excluding the 28% of wideband aerials). In this context, we also assume that both Group B and Group C/D are limited to the channel sub-bands 39–48 and 49–60 respectively. This gives the split of aerials used shown in Figure B.5 below.

The proportion of households with either wideband or Group E aerials which would be affected following a MUX move is calculated as the average between the proportion affected under a theoretical even spread of MUX channels across the bands[110]and the proportion affected assuming a pure weighted transmitter area split (i.e. from Figure B.4). This reflects that in reality the MUXs used in an area will neither be perfectly grouped within the sub-bands nor perfectly evenly spread covering both sub-bands.

For example, the proportion of households with either a wideband or a Group E aerial and receiving multiplex broadcasts only from channels in the range 39 to 60 and which receive at least one of their multiplex broadcasts from one of channels 39 to 48 is calculated as (99%+29%)/2 = 64%.

110 This is 93% in the case of 7 channel moving and 99% in the case of 10 channels moving, as calculated from 1-(number of MUX combinations possible in remaining channels (n=12 or 15))/(number of MUX combinations possible in current channels (n=22)). The number of combinations is calculated using the binomial coefficient $\frac{n!}{k!(n-k)!}$, where n is the total number of channels in the band considered (i.e. 12, 15 or 22) and k is the number of MUX channels received (i.e. 6).

Figure B.5: Calculation of the proportion of households covered by each aerial type across the two highest frequency sub-bands [Source: Analysys Mason, 2012]

Aerial group	Proportion of aerials in Channels 39 to 48	Proportion of aerials in Channels 49 to 60	Proportion of total households[111]
Wideband	28%	28%	17%
Group B	36%	0%	11%
Group C/D	0%	36%	11%
Group E	36%	36%	22%
Total	100%	100%	62%[112]

To summarise the above, the chance of a household being affected by the vacation of ten channels in the sub-band of Channels 39 to 48, for example under the DVB-T2 mitigation strategy, is calculated as:

% wideband and Group E aerials × proportion of these households affected) + (% Group B aerials × proportion of these households affected) + (% group C/D aerials × proportion of these households affected) =

$$\left((17\% + 22\%) \times \frac{99\% + 29\%}{2}\right) + (11\% \times 100\%) + (11\% \times 0\%) = 36\%$$

Figure B.6below summarises the results of this calculation for both the ‘pure DVB-T2 upgrade’ and the ‘move seven channels to 600MHz’ mitigation strategies in each sub-band, showing the percentage of households that use at least one channel in each sub-band and are therefore potentially affected by applying one of the spectrum loss mitigation approaches to save spectrum in that specific sub-band.

In the case of moving a commercial MUX to SFN, it is assumed that every household which receives a commercial MUX will be affected. We note that the portion of total households that may be affected does not need to add up to 100% across the 3 sub-bands (i.e. across each row of the table in Figure B.6) because some households could be affected by applying a mitigation approach in multiple different frequency sub-bands.

	Channels 21 to 30	Channels 39 to 48	Channels 49 to 60
Upgrade to DVB-T2	38%	36%	37%
Move to SFN + upgrade to DVB-T2	91%	91%	91%
Move seven channels to 600MHz	38%	35%	36%

Figure B.6: Proportion of households potentially affected under each mitigation strategy [Source: Analysys Mason, 2012]

111 Where this is calculated as the approximation of households covered by the two highest frequency sub bands $(33\% + 29\% = 62\%)$ multiplied by the average of the proportion of aerials in Channels 39 to 48 and Channels 49 to 60 (for example for Group B, $62\% \times \frac{36\%+0\%}{2} = 11\%$).

112 38% of households are served by channels 21 to 30 resulting in a total of 62% served by channels 39 to 60.

To work out the number of aerials which actually need replacement in each case, these figures must be multiplied by the proportion of aerials which require replacement for a potentially affected household. This is done for each alternative response in turn in the following Sections B.3 to B.5.

B.3 Upgrade to DVB-T2

Following an upgrade to DVB-T2, the total number of MUXs required to deliver current service levels can be reduced from six to four. This means that, theoretically, only 22 channels are required after the upgrade. The exact location of the remaining 22 channels depends on which spectrum is considered to be vacated. We consider saving the 10 channels (relative to today's usage) from each of our three DTT sub-bands in turn.

We note that to calculate the proportion of aerials which will remain in group, we assume that all re-tuned transmitter sites, which were originally using channels that would be vacated, are redistributed evenly among the remaining 22 channels.

The proportion of aerials that require replacement (if affected) is calculated as the percentage of channels not covered (i.e. not within the aerial group's recommended range of channels) after spectrum loss mitigation for each aerial group, less a proportion of aerials which can still operate even when out of band (as discussed in Section B.1). The proportion of all household aerials requiring replacement is calculated from this proportion of aerials requiring replacement at affected households multiplied by the proportion of households affected by the removal of the ten channels from each sub-band (as discussed above in Section B.2).

The calculation of the proportion of receiving aerials requiring replacement are shown in detail in the three tables below (Figure B.7 to Figure B.9) for each of our three DTT sub-bands in turn. For this spectrum mitigation response, more aerials require replacement if spectrum is removed from Channels 21 to 30 than if higher-frequency channels are vacated.

Figure B.7: Aerial in band calculations given 10 channels vacated from UHF Channels 21 to 30 [Source: Analysys Mason, 2012]

Aerial group	Aerial group's recommended channels	Channels used for DTT after move	Channels covered by aerial after move	Estimated split of households	% of channels covered by aerial after move
Wideband	21–68	39-60	22	28%	100%
Group A	21–37		0	72%	0%
Total/weighted average	–		-	**100%**	**28%**
Proportion of aerials able to receive a signal from out–of–group channels					**14%**
Proportion of aerials for households using channels 21–30 requiring replacement i.e. $(1-28\%) \times (1-14\%) =$					**62%**
Proportion of households using a MUX in channels 21–30 (see Figure B.6)					**38%**
Proportion of all household aerials requiring replacement i.e. $62\% \times 38\% =$					**24%**

Figure B.8: Aerial in band calculations given 10 channels vacated from UHF Channels 39 to 48 [Source: Analysys Mason, 2012]

Aerial group	Aerial group's recommended channels	Channels used for DTT after move	Channels covered by aerial after move	Estimated split of households	% of channels covered by aerial after move
Wideband	21–68	21–30, 49–60	22	28%	100%
Group B	35–53		5	36%	23%
Group E	35–68		12	36%	55%
Total/weighted average	-		-	**100%**	**56%**
Proportion of aerials able to receive a signal from out–of–group channels					**14%**
Proportion of aerials for households using channels 39–48 requiring replacement i.e. $(1-56\%) \times (1-14\%) =$					**38%**
Proportion of households using a MUX in channels 39–48(see Figure B.6)					**36%**
Proportion of all household aerials requiring replacement i.e. $38\% \times 36\% =$					**14%**

Figure B.9: Aerial in band calculations given 10 channels vacated from UHF Channels 49 to 60 [Source: Analysys Mason, 2012]

Aerial group	Aerial group's recommended channels	Channels used for DTT after move	Channels covered by aerial after move	Estimated split of households	% of channels covered by aerial after move
Wideband	21–68	21–30, 39–50	22	28%	100%
Group C/D	48–68		3	36%	14%
Group E	35–68		12	36%	55%
Total/weighted average	-		-	**100%**	**52%**
Proportion of aerials able to receive a signal from out–of–group channels					**14%**
Proportion of aerials for households using channels 49–60 requiring replacement i.e. $(1 - 52\%) \times (1 - 14\%) =$					**41%**
Proportion of households using a MUX in channels 49–60 (see Figure B.6)					**37%**
Proportion of all household aerials requiring replacement i.e. $41\% \times 37\% =$					**15%**

B.4 Move of a single MUX to an SFN on Channel 36 and upgrade to DVB-T2

Following the move to an SFN and upgrade to DVB-T2, the total number of MUXs required will also drop to four, though now only 18 channels are required after carrying out this spectrum loss mitigation response. The exact location of the remaining 18 channels again depends on which spectrum is considered to be vacated, and below we consider saving the 14 channels[113] (relative to today's usage) from each of our three DTT sub-bands in turn. As the number of channels vacated is greater than any individual sub-band, it is assumed that the full sub-band being considered is vacated and the remainder of vacated channels are saved from the cheapest remaining sub-band.

While a similar methodology for calculating the in-group aerials is used as for the upgrade to DVB-T2, in the re-planning of the spectrum every household that was inside the previous COM coverage area now has to also be able to receive Channel 36 on its grouped aerial, as one COM MUX will be broadcast using only this channel across the entire country. In addition, the move to an SFN is modelled as incremental to the DVB-T2 upgrade, which means that some aerials will already have been replaced with wideband aerials in the DVB-T2 upgrade and so will not need further upgrade.

In this case the proportion of aerials requiring replacement is broadly similar across the different sub-bands, although slightly higher where Channels 39 to 48 are vacated.

113 A total of 15 channels are vacated but then channel 36 is used for the SFN resulting in a net saving of 14 channels.

Figure B.10: Aerial in-band calculations given 15 channels vacated, primarily from UHF Channels 21 to 30 [Source: Analysys Mason, 2012]

Aerial group	Aerial group channels	Channels used after move	Aerials already replaced	Channels covered by aerial	Estimated split of houses	% of channels covered by aerial after move
Wideband	21–68		0%	18	28%	100%
Group A	21–37		100%	1	18%	100%
Group B	35–53		0%	12	18%	67%
Group C/D	48–68	36, 43–60	0%	0[114]	18%	0%
Group E	35–68		0%	18	18%	100%
Total/weighted average	-			-	**100%**	**76%**
Proportion of aerials requiring replacement due to DVB-T2 upgrade[115]						**30%**
Remaining households where aerials have not already been replaced						**70%**
Proportion of those remaining households potentially affected by the response (see Figure B.6)						**91%**
Proportion of aerials able to receive a signal from out-of-group channels						**14%**
Proportion of remaining potentially affected households requiring aerial replacement i.e. $(1 - 76\%) \times (1 - 14\%) =$						**21%**
Total additional households requiring aerial replacement due to moving to an SFN i.e. $70\% \times 91\% \times 21\% =$						**13%**
Proportion of all household aerials requiring replacement i.e. $30\% + 13\% =$						**43%**

114 Although group C/D aerials cover some of the relevant channels, they do not cover channel 36 and therefore all aerials would require replacing to ensure reception from the SFN MUX.

115 This is calculated as the 24% (calculated in Figure B.7) of households using channels 21-30 and requiring an aerial replacement due to the DVB-T2 upgrade added to the lowest proportion of aerials which would require replacement due to removing a further 5 channels from another sub-band. In this case that is the sub-band of channels 39-48 where 14% of households would require replacement aerials if 10 channels were removed. However, here only 5 channels from this sub-band need to be removed and so additional proportion of aerials requiring replacement is only around 6%.

Figure B.11: Aerial in-band calculations given 15 channels vacated, primarily from UHF Channels 39 to 48 [Source: Analysys Mason, 2012]

Aerial group	*Aerial group channels*	*Channels used after move*	*Aerials already replaced*	*Channels covered by aerial*	*Estimated split of houses*	*% of channels covered by aerial after move*
Wideband	21 - 68		0%	18	28%	100%
Group A	21 - 37		0%	11	18%	61%
Group B	35 - 53		77%	6	18%	85%
Group C/D	48 - 68	21 - 30, 36, 49 - 55	0%	0	18%	0%
Group E	35 - 68		45%	8	18%	70%
Total /weighted average	**-**			**-**	**100%**	**67%**
Proportion of aerials requiring replacement due to DVB-T2 upgrade						**21%**
Remaining households where aerials have not already been replaced						**79%**
Proportion of those remaining households potentially affected by the response (see **Figure** B.6)						**91%**
Proportion of aerials able to receive a signal from out-of-group channels						**14%**
Proportion of remaining potentially affected households requiring aerial replacement i.e. $(1-67\%)\times(1-14\%)=$						**28%**
Total additional households requiring aerial replacement due to moving to an SFN i.e. $79\%\times 91\%\times 28\%=$						**20%**
Proportion of all household aerials requiring replacement i.e. $21\%+20\%=$						**41%**

Figure B.12: Aerial in-band calculations given 15 channels vacated, primarily from UHF Channels 49 to 60 [Source: Analysys Mason, 2012]

Aerial group	Aerial group channels	Channels used after move	Aerials already replaced	Channels covered by aerial	Estimated split of houses	% in group for SFN
Wideband	21–68	21–30, 36, 39–46	0%	18	28%	100%
Group A	21–37		0%	11	18%	61%
Group B	35–53		0%	8	18%	44%
Group C/D	48–68		86%	0	18%	86%
Group E	35–68		45%	8	18%	70%
Total/ weighted average	–			–	**100%**	**75%**
Proportion of aerials requiring replacement due to DVB-T2 upgrade						**22%**
Remaining households where aerials have not already been replaced						**78%**
Proportion of those remaining households potentially affected by the response(see Figure B.6)						**91%**
Proportion of aerials able to receive a signal from out-of-group channels						**14%**
Proportion of remaining potentially affected households requiring aerial replacement i.e. $(1 - 75\%) \times (1 - 14\%) =$						**19%**
Total additional households requiring aerial replacement due to moving to an SFN i.e. $78\% \times 91\% \times 19\% =$						**14%**
Proportion of all household aerials requiring replacement i.e. $22\% + 14\% =$						**37%**

B.5 Move of seven channels to the 600MHz band

The move of seven channels to a different frequency band does not affect the total number of channels required. It is therefore assumed that all transmitters in channels that are not moved remain broadcasting on exactly the same frequencies as before. Below, we consider the requirements for moving the channels from each of our different DTT sub-bands in turn. The percentage of aerials to remain in-group is calculated as the proportion of the seven new channels (Channels 31–37) that are coved by the aerials used in the bands vacated. The aerial types are again assumed to be split evenly among non–wideband aerial households. This analysis shows that no aerials would need to be replaced if spectrum in Channels 21–30 was to be vacated. This is because even the narrowband Group A aerials covering these channels also cover Channels 31–37 in the 600MHz band. If, however, any of Channels 39–60 were to be vacated then a reasonable proportion of receiver aerials would require replacement, as shown below.

Figure B.13: Aerial in band calculations given seven channels moved from UHF Channels 21 to 30 [Source: Analysys Mason, 2012]

Aerial group	Aerial group's recommended channels	Channels used for DTT after move	Number of 7 new channels covered	Estimated split of households	% of new channels covered by aerial after move
Wideband	21–68	28–37, 39–60	7	28%	100%
Group A	21–37		7	72%	100%
Total/weighted average	–		–	**100%**	**100%**
Proportion of aerials able to receive a signal from out-of-group channels					**14%**
Proportion of aerials for households using Channels 21-30 requiring replacement i.e. $(1-100\%) \times (1-14\%) =$					**0%**
Proportion of households using a MUX in channels 21–30 (see Figure B.6)					**38%**
Proportion of all household aerials requiring replacement i.e. $0\% \times 38\% =$					**0%**

Figure B.14: Aerial in band calculations given seven channels moved from UHF Channels 39 to 48 [Source: Analysys Mason, 2012]

Aerial group	Aerial group's recommended channels	Channels used for DTT after move	Number of 7 new channels covered	Estimated split of households	% of new channels covered by aerial after move
Wideband	21–68	21–37, 46–60	7	28%	100%
Group B	35–53		3	36%	43%
Group E	35–68		3	36%	43%
Total/weighted average	–		–	**100%**	**59%**
Proportion of aerials able to receive a signal from out-of-group channels					**14%**
Proportion of aerials for households using Channels 39–48 requiring replacement i.e. $(1-59\%) \times (1-14\%) =$					**35%**
Proportion of households using a MUX in channels 39–48 (see Figure B.6)					**35%**
Proportion of all household aerials requiring replacement i.e. $35\% \times 35\% =$					**12%**

Figure B.15: Aerial in band calculations given seven channels moved from UHF Channels 49 to 60 [Source: Analysys Mason, 2012]

Aerial group	Aerial group's recommended channels	Channels used for DTT after move	Number of 7 new channels covered	Estimated split of households	% of new channels covered by aerial after move
Wideband	21–68	21–37, 39–53	7	28%	100%
Group C/D	48–68		0	36%	0%
Group E	35–68		3	36%	43%
Total/weighted average	**–**		**–**	**100%**	**43%**
Proportion of aerials able to receive a signal from out-of-group channels					**14%**
Proportion of aerials for households using Channels 49–60 requiring replacement i.e. $(1 - 43\%) \times (1 - 14\%) =$					**49%**
Proportion of households using a MUX in channels 49–60 (see Figure B.6)					**36%**
Proportion of all household aerials requiring replacement i.e. $49\% \times 36\% =$					**18%**

Annex C Mobile spectrum value international benchmarking

This annex provides greater detail on the approach we have followed in obtaining benchmarks for the value of mobile spectrum in other international jurisdictions. These benchmarks are used to cross-check the values produced by our detailed modelling of the value of 700MHz spectrum to mobile operators. Our approach to the benchmark calculation can be split into four stages:

- selecting appropriate benchmark data for marginal bidder value
- adjusting to unencumbered lot values
- calculating GBP/MHz/annum figure for the UK based on full spectrum value
- adjusting the full-value estimate to a technical value estimate; that is an adjustment from the DP value to the LCA value.

We discuss each of these stages below.

C.1 Selection of appropriate benchmark data

We chose to narrow down our data set by focusing on the most recent auctions, and in particular those in which bidders were aware of the potential LTE/HSPA+ usage of the spectrum blocks. Specifically, that meant we used only data from auctions which finished in 2008 or later in our analysis.

We then looked more closely at the environment in which these auctions occurred to ensure that we only used data which was directly applicable to the theoretical UK 700MHz band situation (i.e. a highly competitive market and the assumption that spectrum is awarded on a fully competitive basis).

In particular we therefore eliminated those benchmarks that did not fit these criteria or those from auctions dictated by mitigating circumstances. A synopsis of our decisions regarding and reasoning behind any exclusion of these recent benchmarks can be seen in Figure C.1 below.

Figure C.1: Inclusion or exclusion of auctioned spectrum bands in the benchmarks [Source: Analysys Mason, 2012 – note the bands are listed in reverse chronological order of the auctions]

Country	Auction date	Spectrum band auctioned	Decision
Denmark	June 2011	800MHz	Included – however, only the price paid by TDC in the auction is included as the other lot purchased by a consortium of 2 operators was encumbered
France	December 2011	800MHz	Included – however, we note that the benchmark is potentially artificially low due to the hybrid auction/beauty contest nature of the award. This, however, is not easy to adjust for
Brazil	December 2011	850MHz	Excluded – the band was not intended to provide the same nationwide LTE services as we are looking at in the UK case
Portugal	November 2011	800MHz	Excluded – the auction was uncompetitive due to lack of excess demand, as evidenced by every lot being sold at the reserve price
Italy	September 2011	800MHz	Included
South Korea	August 2011	800MHz	Excluded – the main MNOs were prevented from bidding, limiting competition. There is also evidence of strange dynamics, with operators keener on the 2×20MHz of 1800MHz spectrum – surprising, given the emphasis on headline speeds in the market
Spain	August 2011	800MHz	Excluded – it seems there was no excess demand, which may have resulted in artificially low prices
USA	July 2011	700MHz	Excluded – the licences were among those offered in the US 700MHz auction in 2008 (which we include) but remained unsold, or were licences that were re-awarded after a winning bidder defaulted
Sweden	March 2011	800MHz	Excluded – the advanced variety of network infrastructure and spectrum sharing arrangements in place in Sweden diluted competition for this spectrum
Hong Kong	March 2011	850MHz	Included
Germany	May 2010	800MHz	Included – however, we note that the benchmark may be artificially low because of the reverse roll-out coverage obligation. This, however, is not easy to adjust for
USA	June 2008	800MHz	Excluded – we could only find evidence of the sale of one licence, with very limited population coverage
USA	March 2008	700MHz	Included

C.2 Adjustment to unencumbered lot values

We have assumed that any UK award would involve entirely unencumbered spectrum, although this assumption is unlikely to make large differences to the estimates. To do this we compared the prices paid by each operator in the benchmarks included, and removed from our calculation any bids in which the price paid was distorted due to encumbered lots. Specifically, the lowest value lots in the French, Danish and Italian auctions were removed from our benchmarks due to interference issues in these lots. We also removed the unpaired lots from the US auctions as this spectrum is not directly comparable with paired spectrum.

C.3 Calculation of a GBP/MHz/annum value for the UK

The included benchmark data has been used in our calculation of an estimate of the value per MHz of 700MHz spectrum for mobile use in the UK. We have calculated this value using the following steps:

- We calculated a value of (MHz of spectrum × covered population × licence duration) for each of the successful bidders
- We divided the sum of the prices paid in euros at the time by the sum of the MHz of spectrum × covered population × licence duration, giving an average EUR/MHz/pop/annum value of 0.065
- We used the current EUR:GBP exchange rate (1.25) to convert this average into a GBP/MHz/pop/annum value of 0.052
- We multiplied this by the mid-year 2011 UK population to scale up to the GBP/MHz/annum value, giving a result of around GBP3.8 million.

C.4 Adjustment to a technical value estimate

From this full value of the spectrum we isolated the *technical* value, in line with the LCA methodology. The technical value can be difficult to disentangle from other sources of value when considering prices paid by operators, and for the purposes of the indicative valuation we relied on our experience of building spectrum valuation models for operators across a range of countries. In our experience, the technical value often makes up only a relatively small proportion of the full spectrum value.

This should not be surprising when one considers the approach which an operator with an existing grid of sites[116] will take to providing coverage. It is unlikely to be profitable for an operator to roll out LTE coverage to a segment of the population if this involves building a large number of new sites. Therefore operators tend to tailor the coverage which they provide to the spectrum licences which they hold. If an operator has 800MHz or 900MHz spectrum already, then similar coverage levels could be provided using 700MHz spectrum using only existing sites. If an operator has no sub-1GHz spectrum, the approach would still likely be to add new spectrum to existing sites, but this would then result in an expansion in coverage levels.

Conversely, if an operator holds only 2.6GHz spectrum for LTE then it will have a more modest coverage target based on adding this (inferior) spectrum to existing sites but covering less of the population with LTE services as a result. Subsequently acquiring 700MHz spectrum would therefore not constitute large network cost savings (because the operator would likely already have

116 Noting that existing operators generally have a higher total value for new spectrum than potential new entrants and therefore are more likely to be the operators which we should consider in this analysis.

decided not to build large numbers of new sites), though 700MHz would enable an expansion of coverage and service offering. Such an expansion, however, represents *commercial* value rather than technical value or network cost savings.

Naturally, some sites will need to be built by mobile operators for *capacity* as well as for *coverage* reasons. Having additional spectrum will always therefore result in some level of network cost savings. However, this benefit is similar for most frequencies of spectrum, and the proportion of total value which is technical value is therefore likely to be lower for more valuable low-frequency spectrum such as 700MHz.

We estimate that for the 700MHz band the proportion of the full value which is technical value is likely to be between 20% and 50%, with a value towards the middle of this range most likely. This would imply an estimate for the opportunity cost of the 700MHz band in alternative use in the range of GBP0.8–1.9million per MHz for LCA.