Study for the European Commission

Inventory and review of spectrum use:

Assessment of the EU potential for improving spectrum efficiency

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The opinions expressed in this report are those of the authors and do not necessarily reflect the views of the European Commission.

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Executive Summary

This is the Executive Summary of the Final Report for the project "Inventory and review of spectrum use: Assessment of the EU potential for improving spectrum efficiency (SMART 2011/0016)". The project has been conducted by a multi-national team led by WIK-Consult GmbH together with Aegis Systems, Plum Consulting and IDATE.

It is important to understand the Spectrum Inventory in context. It is a key element of the European Union's *Radio Spectrum Policy Programme (RSPP)* that was proposed by the European Commission and enacted by the European Parliament and Council on 15 February 2012. The RSPP calls on the Commission "… to develop practical arrangements and uniform formats for the collection and provision of data by the Member States to the Commission on the existing uses of spectrum." The Commission is also "… to develop a methodology for the analysis of technology trends, future needs and demand for spectrum in Union policy areas covered by this Decision, in particular for those services which could operate in the frequency range from 400 MHz to 6 GHz, in order to identify developing and potential significant uses of spectrum..."

Our Terms of Reference called on us to (1) collect information on both public and private spectrum usage for all 27 Member States in regard to the bands from 400 MHz to 6 GHz in order to create a prototype implementation of the inventory called for by the RSPP, (2) to develop an appropriate methodology for defining and assessing the technical and socio-economic efficiency of spectrum use, and to consider the possible relevance of technical measurements; (3) to analyse the technical efficiency of existing radio spectrum use in the previously noted bands; (4) to compare the efficiency of use of radio spectrum in Europe to that in other regions of the world, and (5) to identify bands where efficiency of use could be improved, and to make recommendations.

In the course of the project, we conducted two public workshops, the first on 10 May 2012 and the second on 6 July 2012.

The Spectrum Inventory and spectrum optimisation at European level

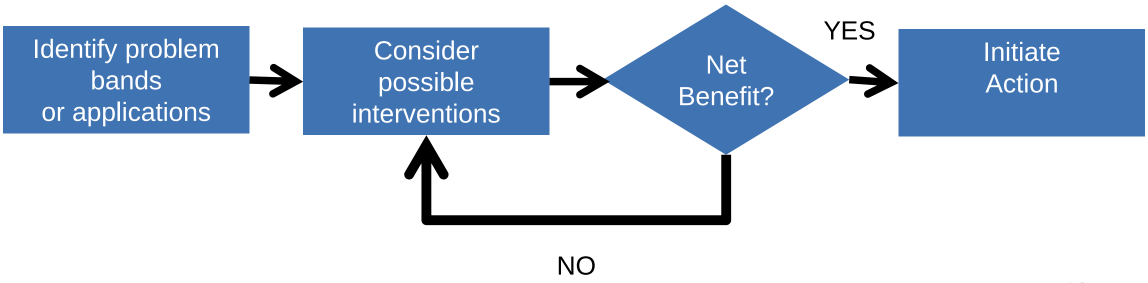
We start from the premise that optimization of spectrum allocation, assignment and use at European level is neither a *fully structured* problem (where all relationships can be identified and understood in advance),[1] nor a totally *unstructured problem* (where relationships are totally unknown and unknowable). Instead, we consider it to be a *semi-structured problem*, where many relationships can be identified in advance, but not all.

1 A few experts have by contrast argued that management of *all* spectrum could be totally automated using market mechanisms. We are fans of market mechanisms, but we think that this view is hopelessly simplistic.

This implies that there is no realistic prospect of a fully automated solution determination of the optimal result; however, there is a potential role for a *Decision Support System (DSS)* to provide automated assistance to human planners. It is in exactly this role that the Spectrum Inventory should be viewed. It is an aid to the decision-maker, but does not substitute for human judgment.

We envision a two stage process, as depicted in Figure 1. In the first phase, the analyst seeks to identify bands or applications that are inefficient or problematic. In the second phase, the analyst considers possible policy interventions that could be attempted, and evaluates the potential costs (including costs to any incumbents) and benefits associated with each possible intervention. This assessment could be performed using the EU's Impact Assessment methodology if desired. If at least one candidate intervention generates an overall societal net benefit, then the Commission can make a judgment as to which intervention is most promising, and can attempt to initiate it, coordinated as appropriate with existing channels such as CEPT and ETSI.

A possible spectrum optimisation process



Source: WIK/Aegis/IDATE/Plum

In and of itself, the Spectrum Inventory including the related toolkit will not determine that spectrum efficiency in a given band or geography should or should not be improved; rather it will *provide an indication that a given band or geography could be used more efficiently and might be worthy of further assessment (phase 2)*.

It is difficult to say in advance exactly what analysis tools would be most useful. We envision a set of spectrum data analysis tools that will use the spectrum inventory's data base and will likely grow over time. Each individual phase 2 analysis of alternative interventions is likely to require tools. These tools should be designed with software reusability in mind to the extent that doing so is practical. The analyst's tool kit of performance modelling and statistical analysis tools is thus likely to grow over time in response to the needs that have been experienced.

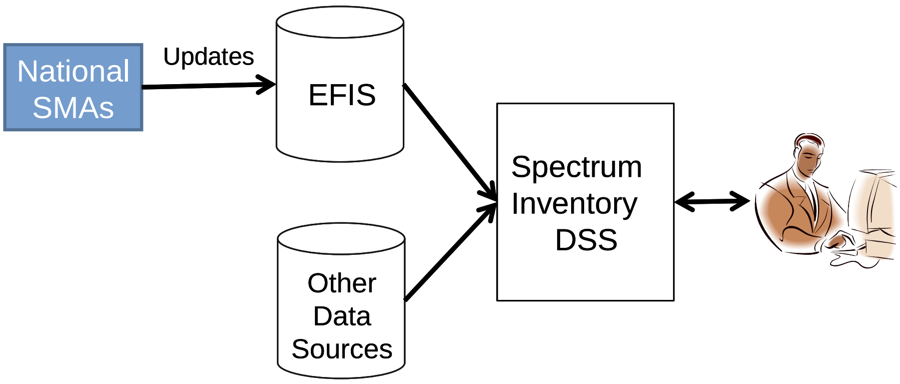
A key question that emerged in the course of our study was the prospective relationship between the eventual Spectrum Inventory and the *ECO Frequency Information System (EFIS)*, an important and useful database of spectrum management information that is managed by the *European Communications Office (ECO)* in Copenhagen. EFIS provides extensive data on spectrum allocations, applications, and rights of use;[2] however, it does not generally provide data on the actual usage of bands.

National Spectrum Management Authorities (SMAs) have invested significantly in tools to maintain and update their portions of the EFIS database, primarily using an update process based on XML.[3] It is important to avoid needless duplication of effort.

We think that integration of EFIS into the Spectrum Inventory process is perfectly feasible. The national SMAs could continue to maintain suitable data in EFIS using the same XML-based tools that they use today. Doing so would imply that the data is updated through a single process, thus avoiding duplicative labour, and also enhancing data consistency. If desired, EFIS could be expanded to incorporate additional data, which could again be maintained using familiar XML-based tools (or their successors as they evolve over time). A periodic "snapshot" of the EFIS database could be downloaded into the Spectrum Inventory database to keep it sufficiently current.

Data that is not suitable for EFIS (for example, because it is commercially sensitive or confidential) could in parallel be directly stored and maintained in the Spectrum Inventory database. The Commission would not be limited to EFIS data.

A possible realisation of interoperability with the EFIS database



Source: WIK/Aegis/IDATE/Plum

2 See http://www.efis.dk/views2/search-general.jsp (viewed 5 March 2012).
3 XML is a generalised mark-up language that is both human-readable and machine-readable. It is often used to represent complex data structures.

Building the prototype Spectrum Inventory data base

Populating the knowledge base was a significant undertaking. In addition to extensive desk research, we conducted many interviews, with quite a few of them face to face. We contacted Spectrum Management Authorities in all of the Member States, and contacted or attempted to contact many additional stakeholders as well (including NATO, ICAO (International Civil Aviation Organization), Eurocontrol, DGAC, IMO-COMSAR (maritime), Inmarsat, EBU (Broadcasting), EUMETNET, ESA, ESOA/SES, CRAF (radioastronomy), APWPT, and the TETRA Association).

This process greatly expanded our understanding of the Spectrum Inventory's functional requirements. For example, it quickly became apparent that application categories maintained by SMAs for use in EFIS were ill-suited to the kind of analysis that we were required to perform. We consequently developed a more concise characterisation comprised of just 14 categories (see Section 3.3.1 and Annex 3 of the Final Report).

Availability and quality of information on spectrum *usage* (e.g. the number of users, or the number of terminals), as maintained in EFIS and also as available at Member State level, was found to vary considerably both between applications and countries. In general we found there was good information about public mobile and broadcast bands, and for some of the aeronautical bands; however, for other services the quality of information was highly variable, ranging from non-existent to quite detailed. Military bands posed particular challenges, as expected, although some national administrations were more forthcoming than others. In terms of actual usage of spectrum, in many cases it is sector stakeholders rather than SMAs that have information, and in some cases very little information on actual usage is available.

A second issue is that there is some inconsistency in the scope and level of detail of the information provided by individual SMAs.

Confidentiality issues appeared during the interview phase. Sensitive information exists both for governmental and for commercial applications.

Defining and assessing the efficiency of spectrum use

Consistent with our Terms of Reference, we considered technical, economic and social efficiency; however, our primary emphasis was on technical efficiency.

A number of general observations quickly became apparent:

- No single efficiency metric will be definitive. Multiple metrics need to be considered in context.
- For rating all forms of efficiency, transparent and repeatable process is important. Quantitative metrics are useful, but in practice qualitative metrics are also required. Metrics must be, as much as possible, objective and verifiable.

- Metrics that seek to measure a possible lack of efficiency should avoid contamination with the proposed solution; otherwise, the analysis becomes complex and possibly circular. Efficiency must be assessed on its own merits.
- In order to keep the analysis manageable, it is necessary to distinguish among:
  - Metrics that relate to the *application* (which may operate in more than one band);
  - Metrics that relate to the *band* (which may support more than one application); and
  - Metrics that relate to possible measures that might be taken to address inefficiencies in the band.

To facilitate comparison across different application groupings, four generic efficiency criteria were identified that can be applied consistently to all applications[4] and frequency bands, namely:

- **Utilisation:** a measure of how much of the available spectrum resource is currently being used and for how much of the time, by each of the applications using a particular band.
- **Demand Trend**: an indicator of whether the current level of demand for a particular application is stable or likely to change significantly in the future. This takes account, for example, of bands that have recently been licensed but not yet brought into use, but where high usage is anticipated once the service has been launched.
- **Technology**: an indicator of the relative spectrum efficiency of the technologies deployed, compared to state of the art benchmarks for the application(s) concerned.
- **Geographic Extent**: An indication of the population or geographic coverage provided (in the case of networks serving the public), or the extent of the national territory where the spectrum resource is being used (for other applications).

Rankings were then applied to each of these four criteria on an intentionally coarse 0-3 scale (e.g. no usage, low usage, medium usage, or high usage). Quantitative, objective data were used wherever it was available (e.g. number of licences or equipment deployments); otherwise, objective qualitative measures were used.

For economic and social value, we considered a range of metrics. In general, our approach has been to focus this analysis on the second phase, i.e. on considering the

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4 By *applications*, we mean the purpose for which the spectrum is used, e.g. cellular, PMR, defence systems, as opposed to the service allocations defined by the ITU which are more generic - fixed, mobile, broadcast.

impact of possible intervention. The value of an application or band is not necessarily dispositive itself, because most interventions do not eliminate the application, and indeed some may improve its effectiveness (albeit perhaps at some cost).

Based on literature review and our own analysis, we developed the following order-or-magnitude assessment of the economic value (relative to 1.0 for the highest valued existing applications) of a range of largely commercial applications in their respective bands.

Index of incremental value/MHz/pop for harmonised allocations by application and frequency band

	400-600 MHz	600 MHz - 1 GHz	1-2.1 GHz	2.1-3 GHz	3-4 GHz	4-6 GHz
Cellular/BWA	0.01	1	0.5	0.1	0.01	0.001
Broadcasting (Terrestrial)	0.5	0.1	0.01	0.001	0	0
PMR/PAMR	0.1	0.1	0.01	0.01	0	0
Fixed links	0.1	0.1	0.005	0.001	0.001	0.001
PMSE[5]	0.1	0.1	0.01	0.001	0.001	0.001
Satellite (civil)	0.1	0	0.005	0.005	0.005	0.001
SRDs[6]	1	1	0.1	0.01	0.001	0.001
WTDS (WiFi)	1	1	1	1	0.1	0.1

Public mobile services for frequencies in the range 700 MHz to 1 GHz are denoted with a value of 1.0. Red colour coding indicates applications that require relatively little additional spectrum (typically less than 10MHz).

Source: WIK/Aegis/IDATE/Plum

The global view

A number of European Member States and a number of countries around the world conduct activities somewhat comparable to the Spectrum Inventory. Some of these are periodic and recurring, while others are one-off affairs as shown in the table on the following page. None of the countries shown has published data on spectrum efficiency that could be compared with the metrics used in this study.

5 Below 1 GHz, the applications are mainly wireless microphones and talkback. Above 1 GHz, wireless cameras and video links are deployed.

6 For SRDs below 1GHz, small amounts of spectrum (1-2 MHz) can be of high value.

Nature and scope of spectrum inventories

Country	Inventory?	Frequency and scope?
Australia	Yes	Updated each year in the five year spectrum outlook
Japan	Yes	Each year a third of the frequencies is assessed: bands below 770MHz; 770MHz-3.4 GHz; above 3.4 GHz
US	Yes	One-off. Main focus is on bands used by federal agencies in frequency range 225-4400MHz
Europe:		
Denmark	No	Not applicable
France	Yes	Annual. Bands are divided into three groups: under 223MHz, 223MHz-5GHz and above 5GHz.
Ireland	No	Not applicable
Netherlands	Yes	Annual for non-government use and three yearly for government use
Sweden	Yes	One off snapshot of the position today and in 2020
UK	Yes	One-off. Government and non-government use addressed by separate processes

Source: WIK/Aegis/IDATE/Plum

Europe has been working assiduously to free up spectrum for mobile and broadband usage, but it is clear from frequency allocation data given in the table below that Japan and Australia have made more spectrum available than Europe has for these purposes.

Spectrum allocated to cellular mobile services for selected countries

	EU	US[7]	Japan[8]	Australia[9]
700/800 MHz	60	70	72 (60)	90
800/900 MHz	70	72	115 (90)	95
1500 MHz	-	-	97 (77)	-
1800/1900 MHz	150	120	210 (115)	150
2Ghz	155	90	135 (120)	140
2.3 GHz	-	25	-	98
2.6 GHz	190	194	120 (60)	140
Others	-	23	-	-
Total	**625**	**594**	**749 (522)**	**713**

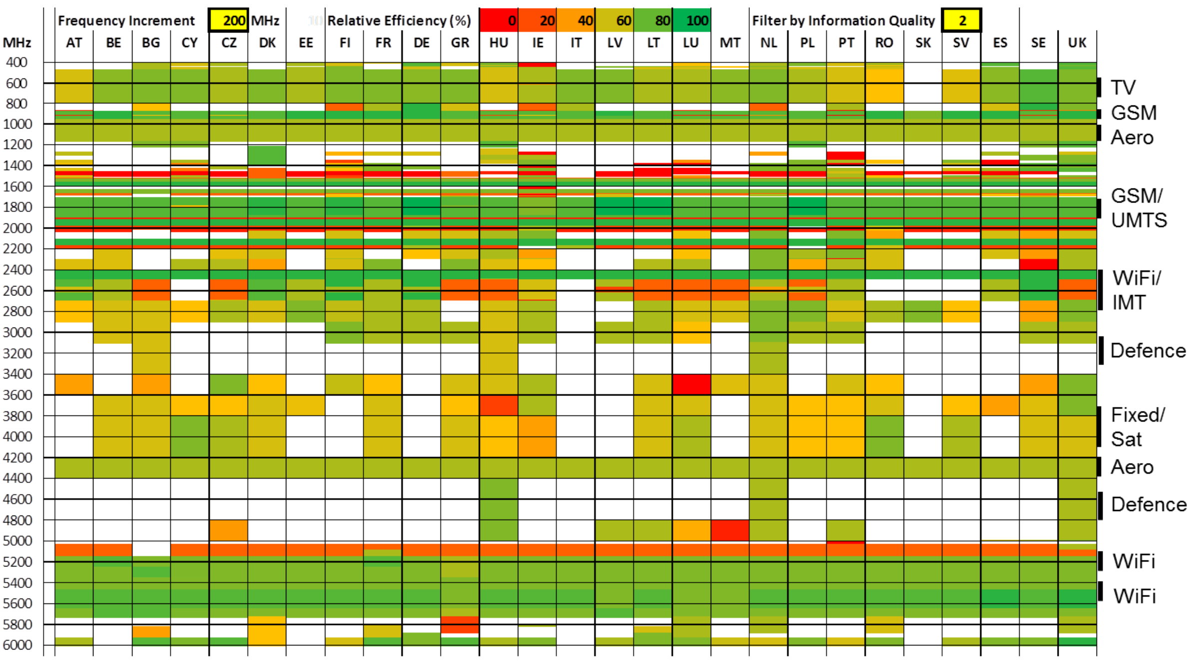
Source: WIK/Aegis/IDATE/Plum

7 Source: FCC - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-11-103A1.pdf
8 Amount allocated shown and amount assigned in brackets. MIC http://www.tele.soumu.go.jp/e/adm/freq/search/actionplan/index.htm; Asia Pacific Telecommunity http://www.apt.int/sites/default/files/APT-AWF-REP-15_APT_Report_on_Mobile_Band_Usage.doc
9 Towards 2020 – future spectrum requirements for mobile broadband, ACMA 2011 http://www.acma.gov.au/webwr/_assets/main/lib312084/ifc13_2011_toward_2020-future_spectrum_requirements.pdf

Technical efficiency of selected bands today

We have analysed relative technical spectrum efficiency across the frequency range 400 MHz to 6 GHz. The colours in the following table indicate the relative value of the overall efficiency indicator, obtained by combining the four individual efficiency criteria (utilisation, demand growth, technology, and geographic coverage). The rating for each band in each country is compared to the highest overall rating in all bands and all countries, which is defined as 100%. Red corresponds to 0%, which effectively means that the band is not in use and is unlikely to be brought into use under current regulatory conditions. Results are shown only for those bands where there is at least a moderate level of information available.

Comparison of technical efficiency, by frequency range and Member State



Findings and conclusions

We summarise here our findings as regards (1) the Spectrum Inventory viewed as an ongoing European spectrum optimisation process; (2) the determination of technical, economic and social metrics; (3) the availability and consistency of data; and (4) the results of our analysis of technical efficiency.

- The Spectrum Inventory as an ongoing European spectrum optimisation process
  - It is useful to think of the spectrum inventory as a *Decision Support System (DSS)* – a set of tools to help a human analyst or decision maker to (1) identify bands and applications, and (2) to evaluate costs and benefits of alternative measures that might be used to improve efficiency.
  - Data management would be a key component of such a DSS, but it should also be assumed that graphic and analytical tools will be needed.
  - The EFIS database is a useful tool, but not all data required for the spectrum inventory is in EFIS, and not all relevant data belongs in EFIS. It is entirely possible to implement a system design that draws on EFIS, and avoids duplicate effort for the Member State SMAs, without inappropriately constraining the spectrum inventory.
- Technical, economic and social metrics
  - Metrics of spectrum efficiency need to also distinguish between *identification* of possibly inefficient use, and *addressing* inefficiencies. The former relates to the *problem*, the latter to the possible *solution*. Metrics to identify the problem should as much as possible be independent of possible solutions.
  - Metrics relevant to inefficiency could relate to (1) the application, which might span multiple bands; (2) the band, which might span multiple applications; or (3) the effects of having a particular application in a particular band.
  - Quantitative metrics have their uses where suitable data is available, but in many cases it will be necessary to use qualitative metrics.
  - Whether metrics are quantitative or qualitative, it is possible to provide an approximate ranking. In this report, we have provided an initial, preliminary view of the relative economic value of applications across a range of bands.
  - In many cases, a measure to improve the efficiency of a band or application does not cause the application to cease operation; more often, there are transitional and long term costs and benefits, but the application need continues to be met. For this reason, the social value of an application (and often the economic value as well) is best considered together with the costs and benefits of measures to address inefficiency, rather than as being itself an index of efficiency or inefficiency.
- Availability and consistency of data
  - In most cases, stakeholders have generally been forthcoming as regards providing data.
  - For some applications, SMAs have data that is useful for estimating usage in a band; for many other applications, SMAs have little data on usage.

  - There is considerable variation in the scope and level of detail of information on spectrum usage held by SMAs.
  - Sector stakeholders have data on usage for some sectors, but not for all.
  - The EFIS database appears to have high consistency with Member State data; however, the Member States do not all record information at the same level of detail, and they do not always record it in the same way.
  - The EFIS categorisation of applications is of limited utility for this study. For our purposes, we have created a more compact and consistent classification scheme. We have reviewed our approach with the ECO, and have generally aligned it with current or potential future EFIS definitions.
- We have identified a number of bands where currently there is either no use at all, or substantial under-utilisation in most Member States.
    - 1.4 GHz former DAB band (40 MHz) – already under consideration for potential future mobile broadband use.
    - 2 GHz TDD and MSS bands (95 MHz) – remain unused in most countries 20 years after being allocated.
    - 5 GHz MLS band (120 MHz) – little or no MLS use, but new aeronautical mobile services are planned.
  - 3400 - 3800 MHz (400 MHz) – formerly used for BWA networks that have failed to gain market share in most EU countries. Parts of the band are used for satellite links, including Inmarsat feeder links, at specific locations. This limits the use of the band for BWA in adjacent areas. For example, much of northern Holland is restricted in order to provide the necessary protection for an Inmarsat gateway station.
  - 3800 - 4200 MHz (400 MHz) – formerly used for point-to-point links, but use has declined due to migration to fibre and higher frequency bands. There is continued use by fixed satellite terminals, but these should be capable of sharing with other terrestrial services on a co-ordinated basis.
  - 5725 – 5875 MHz (150 MHz). Licence exempt / light licensed band identified for BWA deployment, but little or no take-up in most Member States.
- In other cases, usage varies significantly between Member States, limiting the scope for future harmonisation. Consider:
  - PMR bands (406 - 470 MHz)
  - fixed link bands around 1.4 GHz
  - aeronautical radar band at 2.8 GHz
  - 3.1 - 3.4 GHz and 4.4 - 4.8 GHz (mainly defence use).

1 Introduction

This is the Final Report for the project "Inventory and review of spectrum use: Assessment of the EU potential for improving spectrum efficiency (SMART 2011/0016)". The project has been conducted by a team led by WIK-Consult GmbH together with Aegis Systems, Plum Consulting and IDATE – a multi-national team that has conducted several successful projects for the Commission in the past.

The project comprises a pilot programme for the Commission's spectrum inventory (see Section 1.1). The project is strategic, complex, and unusually challenging. We are honoured to have been awarded this task, and have done our utmost to ensure a useful outcome.

1.1 The need for a spectrum inventory

The European Commission adopted its proposal for a first *Radio Spectrum Policy Programme (RSPP)* on 20 September 2010, and the European Parliament and Council approved the RSPP on 15 February 2012. The RSPP is a key element of the amendments to the regulatory framework for electronic communications that were enacted in November 2009.

The RSPP sets out the guiding principles and the objectives to be followed by Member States and EU institutions in the field of radio spectrum, and indicates the initiatives that are taken to allow a swift implementation of these principles and objectives.

In order to address weaknesses that have been identified in European spectrum management to date, and notably in order to underpin the increasingly sensitive choices that will need to be made, it will be necessary to develop a stronger and more coherent vision of the manner in which spectrum is used. The Commission has identified the need for a comprehensive inventory of spectrum use – including not only allocations, applications,[10] and rights of use, but also actual usage – as a key element of this strategic vision.

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10 By *applications*, we mean the purpose for which the spectrum is used, e.g. cellular, PMR, defence systems, as opposed to the service allocations defined by the ITU which are more generic – fixed, mobile, broadcast.

1.2 Relationship of this exploratory study to the Commission's production spectrum inventory

The spectrum inventory has been the subject of ongoing discussions between the Commission and various stakeholders, notably including the RSPG.

Our Terms of Reference for this study explicitly call for us to collect stakeholder data, but they do not specify how this collection relates to the ultimate spectrum inventory, nor do they call on us to make recommendations as to what the relationship should be.

As a practical matter, it became abundantly clear over the course of the study that we could not meaningfully execute our required tasks without first offering stakeholders and the Commission a vision of what the ultimate spectrum inventory might be, how it might be used, and how it might possibly relate to existing data sources such as the EFIS database that is maintained by the ECO in Copenhagen. We emphasise that our views have no particular official standing, and that we as the study team have no control over what will eventually be implemented; nonetheless, we have offered our suggestions, we note that they appear to have been well received at the RSPG #27 meeting in Brussels on 29 February 2012, and we feel that our suggestions merit serious consideration by all concerned.

We sketch out these suggestions, together with our overall vision of how the ultimate Spectrum Inventory might function as part of a broader spectrum optimisation process at European level, in Chapter 2 of this Interim Report.

We further emphasise that this report, and indeed this project, should be viewed as an exploratory effort. We have sought to:

- Determine what data is useful.
- Determine what data is reasonably available.
- Experiment with different efficiency measures.
- Experiment with different ways to analyse data.
- Experiment with different ways to organise and present data.

1.3 Scope of the study

Our Terms of Reference require us to concentrate on gathering information on both public and private spectrum usage for all 27 Member States in regard to the bands from 400 MHz to 6 GHz. In addition, we are gathering data about the PPDR TETRA bands (380-385 MHz and 390-395 MHz), and the bands from 174 MHz to 230 MHz (the former analogue TV broadcast Band III). This information must be reported to the Commission in a consistent format.

We are required to develop an appropriate methodology for defining and assessing the technical and socio-economic efficiency of spectrum use, and to consider the possible relevance of technical measurements.

We are required to analyse the technical efficiency of existing radio spectrum use in the previously noted bands, and to provide our results in an electronic database.

We are called on to compare the efficiency of use of radio spectrum in Europe to that in other regions of the world, and to identify bands where significant economic growth potential exists.

We are to identify bands where efficiency of use could be improved, and to make recommendations.[11]

The Terms of Reference envision two public workshops. One of these is now scheduled for 10 May 2012, the other for 6 July 2012.

1.4 Methodology and process

Our approach to the problem draws on classic methodologies.

We are conducting extensive desk research, and are interviewing a great many stakeholders – not only Spectrum Management Authorities (SMAs) in all Member States, but also a wide range of sector stakeholders. We are attempting to meet face to face with every stakeholder – a substantial burden, but in our view the best way to ensure alignment and to motivate stakeholders to provide the necessary information. We leave a questionnaire with the stakeholder, and solicit responses within a few weeks. Where information is already publicly available (for example, in Frequency Allocation Tables or in the publicly available EFIS database), we seek to enter it ourselves rather than burdening the stakeholder; however, we provide the stakeholder with the opportunity to verify the information (see Chapter 3).

Operationally, we have stored the data in spreadsheets for easy transfer within the team and to facilitate subsequent analysis. Structuring the data so as to make it useful and intelligible has itself involved a range of technical challenges.

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11 It is worth noting that our Terms of Reference place little or no emphasis on the assessment of spectrum *demand*; indeed, we understand that the Commission intends to address these questions separately. Our approach is to look for opportunities to improve spectrum efficiency generally, and to de-couple the identification of inefficiency from the satisfaction of demand. We do not think that it is meaningful to try to identify a single number as the demand for spectrum – improved efficiency always generates benefits, which must always be weighed against the costs of achieving those benefits. The level of supply and demand affects the economic value of the benefits, but it is possible (and preferable) to identify inefficiency independent of supply and demand. Our approach is thus somewhat different from that which the RSPG takes in their opinion of the Review of Spectrum (RSPG 12-408).

Defining metrics of efficiency requires complex thought and analysis. We are breaking new ground. The RSPG has just released a new opinion on the technical, economic and social efficiency, but it restricts itself to WAPECS bands and as a practical matter it provides little or no useful guidance to our work. Nonetheless, we believe that we are making headway with the problem (see Chapter 4).

In terms of applying metrics of technical efficiency to the bands from 400 MHz to 6 GHz, we found that no clear definition of technical spectrum efficiency exists currently that can be applied to all services. We therefore based our assessment on how heavily used each band is in each country, compared to other bands and other countries where similar applications are deployed (see Chapter 6).

1.5 Structure of this document

The second chapter of this report offers (as previously noted) a possible vision as to how a spectrum inventory might be used in production to assist a human analyst in (1) assessing technical and socio-economic efficiency, and (2) evaluating alternative measures that might be considered in order to improve efficiency of specific bands in specific geographic areas. Chapter 3 reviews the process that we are using to gather stakeholder data, and provides an overview of the data that we have collected to date. Chapter 0 discusses candidate metrics of technical efficiency and of socio-economic efficiency. The chapter includes a discussion of technical monitoring as a possible means of assessing technical efficiency. Chapter 5 contains international benchmarks, including non-EU comparisons. Chapter 6 reviews the technical efficiency of selected bands. Chapter 7 contains our findings and recommendations.

In addition, we have provided the following Annexes to this report:

- Annex 1: Measures of socio-economic benefits
- Annex 2: Estimates of the economic and social value of spectrum
- Annex 3: Background data for the international benchmarking exercise

2 The spectrum inventory as a Decision Support System (DSS)

The Terms of Reference for this study do not call for a conceptual model as to how the Spectrum Inventory should eventually be used in production; however, in the course of the project, it became clear that a conceptual model was required in order to ensure alignment between the Commission and the Member States.

As a preliminary, we consider it important to distinguish among:

- The *process* used to identify candidates for efficiency or effectiveness, and to develop measures to address them;
- The specific *metrics* that could be gathered and used to measure spectrum efficiency; and
- The *measures* that could then be taken to enhance efficiency or effectiveness.

Implicit in this view is our belief that recognition that the technical or economic efficiency with which a band is used in a given geography leaves room for improvement must, in our view, be de-coupled from what measures (if any) might be employed to improve efficiency. To do otherwise would risk distorting the analysis.

2.1 Semi-structured problems and the DSS

We start from the premise that optimization of spectrum allocation, assignment and use at European level is neither a *fully structured* problem (where all relationships can be identified and understood in advance, and where a computer could in principle derive an ideal answer),[12] nor a totally *unstructured problem* (where relationships are totally unknown and unknowable). Instead, we consider it to be a *semi-structured problem*. This means that many relationships can be identified in advance, and many can be fully understood, but not all. This also implies that there is no realistic prospect of a fully automated solution determination of the optimal result.

This implies that there is a potential role for *Decision Support Systems (DSS)* to provide automated assistance to human planners, and it is in exactly this role that the Spectrum Inventory should be viewed. It is an aid to the decision-maker. It provides automated assistance, but does not substitute for human judgment.

The Spectrum Inventory, viewed as a DSS (or component of a DSS), could play an extremely important role, but it is important to recognise its inherent limitations and thus to approach the task with a suitable degree of humility.

12 A few experts have by contrast argued that management of *all* spectrum could be totally automated using market mechanisms. We are fans of market mechanisms, but we think that this view is hopelessly simplistic.

Thinking of the spectrum inventory, together with analytic tools and trend and cluster recognition tools, as a DSS lends clarity to our analysis. It helps clarify what such a system could achieve, and also what it is unlikely to achieve. It also enables us – and perhaps those who will follow us – to draw on a substantial body of established literature and experience in the field of computer science.

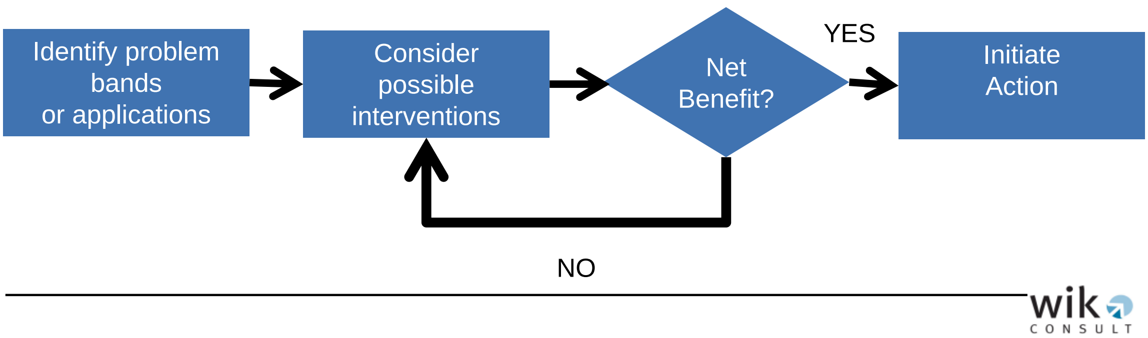
2.2 Potential uses of the DSS

Bearing in mind the inherently semi-structured character of the problem, potential roles for the Spectrum Inventory including its supporting DSS tools include:

- to help the analyst to identify candidate bands and geographies for improvement, and
- to further assist the analyst in evaluating likely costs and benefits of possible measures to improve efficiency.

We envision a two stage process, as depicted in Figure 1. In the first phase, the analyst seeks to identify bands or applications that are inefficient or problematic. In the second phase, the analyst considers possible policy interventions that could be attempted, and evaluates the potential costs (including costs to any incumbents) and benefits associated with each possible intervention. This assessment could be performed using the EU's Impact Assessment methodology if desired. If at least one candidate intervention generates an overall societal net benefit, then the Commission can attempt to initiate the change, coordinated as appropriate with existing channels such as CEPT and ETSI.

Figure 1: A possible spectrum optimisation process



In and of itself, the Spectrum Inventory including the related toolkit will not determine that a given band or geography should or should not be improved; rather it will *provide an indication that a given band or geography could be used more efficiently and might be worthy of further assessment*.

In any specific case, the analyst will need to dig deeper. Considering the manner in which the band is used in the geographic area of interest, how should the metrics of technical efficiency be interpreted? What changes could be considered, and what are their potential ramifications? What are the impacts on adjacent bands and geographic areas? What are the real economic and social costs and benefits of making the proposed change?

2.3 Metrics for spectrum efficiency

Identification of suitable metrics for technical and for socio-economic efficiency is a complex process. We discuss metrics at length in Section 7.2. For now, it is sufficient to establish a few general guidelines in order to properly ground the discussion of the process to be followed in analysing efficiency and of addressing lack of efficiency:

- It is important to avoid over-simplifications.
  - Any metric must be understood in context.
  - No single metric is likely to be definitive; rather, multiple metrics should be considered holistically.
- Transparent and repeatable process is important.
  - Quantitative metrics are useful, but in practice qualitative metrics will surely also be required.
  - It is crucial that metrics be, insofar as possible, objective and verifiable.
- Metrics that seek to measure a possible lack of efficiency should avoid contamination with the proposed solution; otherwise, the analysis becomes complex and possibly circular. Efficiency should be assessed on its own merits.

2.4 Data management versus data analysis

Many different kinds of DSS have been implemented in practice. Typically, they incorporate substantial data or knowledge, reflect an assumed model of the underlying problem, and either make decisions or (as is more appropriate in this case) assist the analyst in making decisions.

In this case, it is difficult to say in advance exactly what analysis tools would be most useful. We envision a set of spectrum data analysis tools that will use the spectrum inventory's data base and will likely grow over time. Each individual phase 2 analysis of alternative interventions is likely to require tools. These tools should be designed with software reusability in mind to the extent that doing so is practical. The analyst's tool kit of performance modelling and statistical analysis tools is thus likely to grow over time in response to the needs that have been experienced.

The DSS also includes a user interface. Some would also consider the user or analyst to comprise part of the Decision Support System.

2.5 Addressing inefficiencies that have been identified

There are a number of potential measures that could be undertaken to enhance spectrum efficiency and/or effectiveness. The most obvious include:

- Spectrum re-farming to re-allocate or reassign a band in a specific geographic area;
- Employing new technology to improve the efficiency of use of spectrum in its current application;
- Enabling increased sharing of the band in question in the relevant geography; or
- Establishing harmonization across a broader geographic area, or eliminating or narrowing harmonisation that is already in place.

There could also be a conscious decision that no action is warranted.

Each of these has complex implications in terms of benefits and costs. The benefits will tend to be application-specific, and will need to be analysed on a case-by-case basis. Some aspects of cost, however, have a generic element that could be represented in the Spectrum Inventory and/or automatically generated from its content.

Re-farming, for example, entails a number of predictable costs, including:

- The opportunity cost of allocating/assigning the spectrum to the proposed use, rather than some other use;
- The re-farming cost of changing the use, including engineering costs, equipment costs, the cost of downtime/avoiding downtime, deployment costs; and
- Any impact (negative or positive) on the incumbent application, assuming that it is still needed.

There is some variability in opportunity cost, but it is reasonable to use auction results to date to establish a rough estimate for any frequency band of interest, expressed in measures such as euro per MHz/POP. This metric is normalised relative to the population covered; however, like any metric, it has its strengths and weaknesses.

The cost of re-farming is highly dependent on the incumbent application and on the cost and age of associated equipment, but there is experience (in France and in the US, for example) with paying the costs of re-farming. This experience could be used to set rough upper and lower bounds for re-farming costs; however, it should be noted there may be inherent bias in these figures, given that the bands that were chosen for re-farming are likely those bands that were perceived as being easy to re-farm in the first place.

In the case of opportunity costs and of re-farming costs, these will produce only rough estimates. In a second phase, the human analyst should supplement these rough figures of merit with situation-specific data.

The decision that some action is warranted will tend to be clear where one or more candidate actions can be shown to make some better off and none worse off, even after taking into account the transaction costs associated with implementation (this situation is said to be *Pareto optimal*).

Action can, however, also be warranted if a candidate action can achieve a Pareto optimal outcome by arranging sufficient compensation from those who are made better off to those who are made worse off so that all would end up no worse off than before (this situation is said to fulfil the *Kaldor-Hicks criterion*).[13]

2.6 Linkages to EFIS and other systems

The *ECO Frequency Information System (EFIS)* is an important and useful database of spectrum management information that is managed by the *European Communications Office (ECO)* in Copenhagen. It implements EC Decision 2007/344/EC on the harmonized availability of information regarding spectrum use in Europe.

EFIS provides extensive data on spectrum allocations, applications, and rights of use.[14] Our study has drawn heavily on EFIS data. At the same time, it must be noted that EFIS does not generally provide data on the actual usage of bands.

National Spectrum Management Authorities (SMAs) have invested significantly in tools to maintain and update their portions of the EFIS database, primarily using an update process based on XML.[15] Several SMAs have made it clear, both in our interviews and in positions taken by the RSPG, that they consider it important to avoid needless duplication of effort.

We consider the concerns of the SMAs to be well founded. If a Commission spectrum inventory were totally disconnected from EFIS, not only would duplicate effort be required to maintain substantially overlapping data in two different places, using two

13 For that matter, action might possibly be warranted even if Kaldor-Hicks is not fulfilled. For example, some party is made slightly worse off, but others are made much better off.
14 See http://www.efis.dk/views2/search-general.jsp (viewed 5 March 2012).
15 XML is a generalised mark-up language that is both human-readable and machine-readable. It is often used to represent complex data structures.

different processes, but also data inconsistencies between the two would be practically inevitable.[16] We consider it important to avoid this going forward.

Our Terms of Reference for the project do not call for us to deal with this issue, but it was in fact necessary to address it in order to ensure alignment between the Commission and the SMAs so as to be able to get on with our work. Once we properly understood the problem, at least one workable solution became obvious, and we offer it here.

First, we observe that the Commission's spectrum inventory has needs that go beyond those of EFIS. As previously noted, the eventual inventory must be accompanied by graphic and analytic tools to aid the analyst. Data on actual usage will be needed, not just on allocations, applications and rights of use. The inventory might draw on additional data sources, some of which are non-public (confidential, proprietary, or both). Finally, while EFIS contains objective data that can play a role in developing measures of efficiency, our sense is that the efficiency assessments themselves should not be stored in EFIS.

For data that is suitable for EFIS, we see no reason why it could not continue to be maintained in EFIS. The national SMAs could use the same XML-based tools that they use today, or any successor update process that might evolve over time. Doing so means that the data is provided once to ECO, and updated through a single process. This serves both to avoid needless, duplicative labour, and also to ensure data consistency.

Assessment of spectrum efficiency as part of the inventory process is likely to require additional data beyond that which currently exists in EFIS, in particular relating to the actual deployment or implementation of applications identified in EFIS. Extensions to EFIS could be accommodated through existing processes. New fields of domains could be coordinated through existing EFIS management processes; in other words, EFIS could be expanded to incorporate additional data, which could then be maintained through the familiar processes (or their successors as they evolve over time).

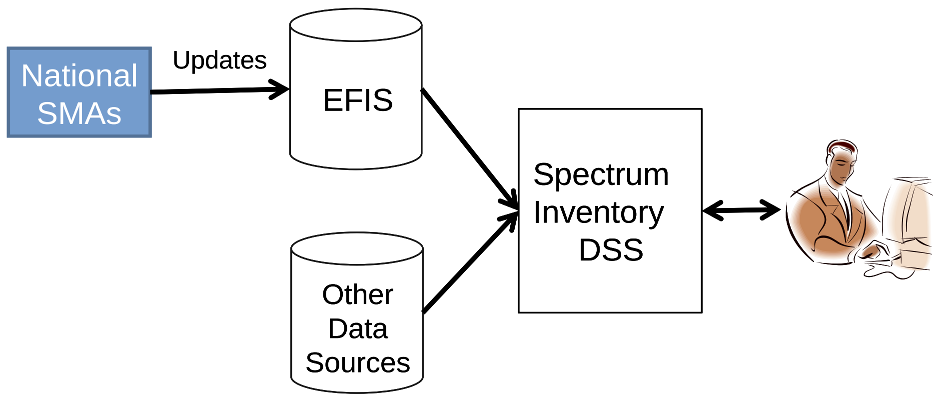
The Commission's spectrum inventory does not require real time access to EFIS, so far as we can see. The strategic planning undertaken by the Commission does not depend on real time accuracy. A "snapshot" of the EFIS database could be taken every three months, or every six months. A similar process (using CSV/spreadsheet data) has been used, or is about to be used, to create an Asia-Pacific version of EFIS, and to periodically provide EFIS data to NATO.

Figure 2 shows how this could work. The SMAs would update EFIS, presumably using existing XML-based update tools, just as they have for years. EFIS would provide data to the Commission's spectrum inventory DSS, presumably using a CSV-based data

16 There is an old Dutch proverb that one should never go to sea with two compasses.

extraction. The Commission's spectrum inventory DSS (including both data management and analysis tools) would draw on EFIS data, but might also draw on other data sources in parallel.

Figure 2: A possible realisation of interoperability with the EFIS database



We believe that this is a straightforward and relatively simple solution that addresses all of the concerns that have been expressed. We encourage the Commission and the national SMAs to consider it.

3 Detailed stakeholder information

Gathering information from a large number and wide range of stakeholders, including but not limited to Member State SMAs, has been an intense process. Fortunately, the interviewees have generally been helpful and responsive.

3.1 Methodology and process

The collection and analysis of the current use of spectrum in the European Union is based upon an initial desk research and interviews with stakeholders. In addition, the input from the first of the two public workshops is expected to be a valuable resource for our analysis.

Desk research

The initial desk research enabled us to gather publicly available information on current spectrum use for each Member State by frequency band and application, along with any plans for change of use. The sources used for this phase of the study include:

- National spectrum registers.
- The EFIS database and the European Common Allocation Table (ECC Report 25).
- CEPT surveys of the use of bands (e.g. ECO Report 3 on licensing of mobile bands, ECC report 173 on Fixed links and the recent survey of use of the 876-880/921-925 MHz band allocated to GSM-R and in the band 1452-1492 MHz allocated to broadcasting services).
- The ITU database of digital broadcasting assignments and allotments under the 2006 Geneva plan (GE-06).
- Published national data on the use by band or application (from the spectrum agency, regulator, trade associations or major users) and as given in national frequency allocation tables or frequency registers.
- National surveys of spectrum use and plans for future release that have been published.
- Plans for technology and service enhancements for services that are international in nature, such as aeronautical, maritime and satellite services.

As we anticipated, the data is partial in terms of the country coverage and does not fulfil the level of detail required for the analysis. This task was conducted in the first month of the study. Additional desk research is taking place as a continuous process as some interviews provide inputs and directions which need to be further detailed.

Survey

The stakeholder survey comprises:

- Face-to-face interviews for SMAs, unless it is agreed with the MS representative that a phone interview is sufficient. Some interviews were made in Geneva during the World Radiocommunications Conference 2012 which gathered the spectrum experts from national administrations and from the industry.
- Face-to-face or phone interviews with other key stakeholders.
- Email questionnaires for other stakeholders (when additional information is required, a follow-up call was made).

At the end of the process for each stakeholder, we have reviewed the data we have gathered for validation. The key objectives of the survey are to collect data for frequency ranges agreed with the Commission and structured around the frequency bands as listed in the European Common Allocation Table concerning:

- The services and applications using the bands.
- Density and geographical scope of actual use (e.g. whether regional, national or pan-European).
- Availability of vacant spectrum.
- Growth trends (is use rising or falling?).
- Technology used by each service/application (including historic and projected developments).
- Planning criteria used.
- Licensing approach (e.g. individual rights of use, collective use, exclusive or shared assignments).
- Technical criteria applied to each services (e.g. as specified in CEPT and ETSI harmonization arrangements).
- Agreements and co-ordination difficulties between users in the bands and between bands, including potential problems where different band plans or incompatible services / technologies are deployed either side of a border.
- International co-ordination arrangements and issues.

3.2 Building the knowledge base

A key focus of our stakeholder interviews is the spectrum management authorities (i.e. entities that manage some or the entire spectrum in each country). Some countries have a single SMA, while others divide management of the spectrum resource depending on the use of the bands (e.g. defence or broadcasting use may be separately managed).

Table 1: Spectrum Management Authority (SMA) interviews

Countries	Stakeholders
Austria	RTR/Bmvit: f-to-f 9/04 and detailed written information provided
Belgium	BIPT: phone 24/01
Bulgaria	MTITC: no answer
Cyprus	MCW: answers by email
Czech Rep	CTU: f-to-f Geneva; more info by email
Denmark	ERST: phone 25/01
Estonia	F-to-f 6/04 and detailed written information provided
Finland	FICORA: f-to-f 30/01
France	ANFr: f-to-f 12/01 MoD: no answer to request for interview
Germany	Bnetza f-to-f 13/01 and detailed written information provided BMWi f-to-f 20/01
Greece	EETT: detailed written response received
Hungary	NMHH and Ministry: f-to-f discussion held 9/3; detailed written information provided
Ireland	COMREG and DCMNR: Meetings held, detailed information provided
Italy	Ministry of Economic Development: phone + written answer, but no detailed information was provided
Latvia	Electronic Communications Office: f-to-f 31/01 Ministry of Transport: f-to-f 31/01 Ministry of the Environmental protection and Regional development: written answer SPRK: written answer
Lithuania	RRT: f-to-f Geneva
Luxembourg	ILR: f-to-f Geneva 8/02 + answers by email
Malta	MCA: f-to-f Geneva 14/02 + more details by email
Netherlands	Agentschaptelecom and Ministry of Defence: meetings held and detailed written information provided.
Poland	UKE: will send answers by email

Portugal	Anacom: detailed written input provided
Romania	Ancom: Detailed written response received
Slovak Rep	Teleoff: no answer
Slovenia	APEK: f-to-f Geneva
Spain	Ministerio de Industria, Turismo y Comercio: interview 25/04 + answers by email
Sweden	PTS: phone – 31/01; detailed written information provided
United Kingdom	Ofcom and Ministry of Defence: meetings held, detailed information provided

Legend: f-to-f = face-to-face

In addition, we approached international organisations (e.g. NATO, Eurocontrol, IMO) and industry participants (e.g. equipment manufacturers) to gather supplementary information that is not supplied by national SMAs (e.g. information on changing sector needs and technology or equipment innovations that may facilitate efficiency enhancement in the future).

Table 2: International organisation interviews

Organisations	
NATO	f-to-f Geneva Mr Poplawski
ICAO (International Civil Aviation Organization)	Contact attempted, no input received
Eurocontrol	Contact attempted, no input received
DGAC	f-to-f Geneva 15/02
IMO-COMSAR (maritime)	No response
Inmarsat	f-to-f Geneva 16/02
EBU (Broadcasting)	Phone 13/03
EUMETNET	Phone 10/01
ESA	Phone 17/01
ESOA/SES	f-to-f Geneva 15/02
CRAF (radioastronomy)	Phone 16/01
APWPT (PMSE)	Contact attempted, no input received
TETRA + Critical Communications Association	Phone 13/03

3.3 Key findings

Stakeholders have in most cases been helpful and responsive. The work is already generating some interesting results.

3.3.1 Categorisation of use

One of the objectives of the spectrum inventory process is to undertake analysis of spectrum efficiency across a wide frequency range (400 MHz to 6 GHz), which covers a large number of applications with very different technical and functional characteristics. To keep the analysis at a manageable level and facilitate comparison between bands and national usage, we decided to group together particular services or applications that share similar technical or functional characteristics and to which similar efficiency metrics might be applied. Since the existing EFIS database is likely to form a principal input of source data for the inventory, consideration was also given to how such application groupings could be made compatible with the existing application definitions used in EFIS.

EFIS uses a three layer hierarchy of applications, as defined in ECC Decision (01)03. There are currently 12 Level 1 applications, which are further subdivided into 89 Level 2 definitions and over 150 Level 3 definitions. In some cases, the individual applications covered by an existing Level 1 definition are sufficiency similar for the same Level 1 definition to be used as one of the groupings for the inventory analysis. However, in other cases the Level 1 definitions were found to be too broad in scope to apply a single set of efficiency metrics. For example, the Level 1 application “Land Mobile” does not differentiate between cellular services and private mobile radio, which tend to use spectrum in a very different way and are generally subject to quite different licensing processes. In other cases, such as aeronautical and maritime, it was considered that similar metrics could be applied to multiple Level 1 categories.

After careful consideration of the metrics that might be applied to different applications, we decided to adopt an approach based on fourteen application groupings, some of which correspond to existing EFIS level 1 or 2 applications, whilst others cover several applications on the basis that these have similar technical and functional characteristics. To facilitate exchange of data between EFIS and the inventory, each EFIS Layer 2 application has been associated with a specific application grouping for the purposes of efficiency analysis within the inventory.

The fourteen proposed application groupings are:

1. Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)
2. Broadcasting (Terrestrial)
3. BWA / Cellular

4. Defence Systems
5. Fixed Links
6. Intelligent Transport Systems (ITS)
7. Meteorology
8. PMR / PAMR
9. PMSE
10. PPDR
11. Radio Astronomy
12. Satellite Systems (Civil)
13. Short Range Devices (SRDs)
14. Wideband data transmission systems

3.3.2 Availability of data

Availability and quality of information on spectrum *usage* (e.g. the number of users, or the number of terminals) was found to vary considerably both between applications and countries. In general we found there was good information about public mobile and broadcast bands, and for some of the aeronautical bands; however, for other services the quality of information was highly variable, ranging from non-existent to quite detailed. Military bands posed particular challenges, as expected, although some national administrations were more forthcoming than others. In terms of actual usage of spectrum, in many cases it is sector stakeholders rather than SMAs that have information, and in some cases very little information on actual usage is available.

3.3.2.1 Military or sensitive data

Very limited information is available from most SMAs on usage of defence spectrum. Countries such as Cyprus and Lithuania do not give detailed information, but indicate which frequency bands are used for defence purposes. The UK and Netherlands Ministries of Defence have provided information on which bands are used for which applications, but only indicative data on how heavily these bands are used.

Information on defence spectrum is available at national level and is NATO unclassified; however, NATO indicates that their rules would not permit NATO to disclose detailed information on specific bands to the EU unless some formal arrangement to that effect were put in place.

Most NATO bands are below 400 MHz, and frequency bands above 400 MHz are harmonised.

Non-NATO defence spectrum may offer a greater opportunity for European coordination through the RSPP than NATO spectrum, because the relationship between the EU and the Member States is more straightforward than that between the EU and NATO.

Warsaw Pact military systems were historically used in many eastern European countries. The incompatibilities associated with this legacy military usage of spectrum are declining in relevance over time. Former Warsaw Pact members have moved quickly to decommission old equipment and to replace it with gear that conforms to NATO allocation plans.

Sharing between military and civilian aeronautical users of radars makes it difficult to identify the real usage of the associated frequency bands.

3.3.2.2 Usage data

As expected, availability of usage data ranges from almost no information to a lot of details. In the first category, only the National frequency allocation table and/or the details entered into EFIS are available. The most favourable cases are countries which publish detailed status of spectrum usage and provide access to online databases. Some countries already have internal electronic data bases but some are still relying on paper documents (e.g. Latvia). Many countries have no data base and no information at all on spectrum usage. The following examples of data bases were identified during the first phase of the study but should not be considered as an exhaustive list:

- Denmark: an on-line frequency register is available. The interactive frequency plan provides direct links to the frequency register in order to see the licenses for specific frequency bands.
- Finland: an additional database (or database based web service) is under consideration to provide better access to UHF frequency band 470-790 MHz for radio microphones and cognitive radio systems
- France: ANFr has established data bases in collaboration with spectrum users ("affectataires"). They contain detailed information on spectrum usage.
  ARCEP, the telecommunications NRA, also has a spectrum register publicly accessible on its web site.
- Netherlands: a frequency register is available on-line and information on actual spectrum use based on monitoring is published for certain frequency bands.
- UK: A register of tradable licences is available online and accessible via EFIS.[17]

17 See http://spectruminfo.ofcom.org.uk/spectrumInfo/licences.

Transmission site data bases are also available in some countries following electromagnetic concerns from the population:

- Denmark: the “mastdatabasen” is publicly available.[18]
- France: the Cartoradio data base provides information on sites used for PMR, broadcasting and cellular.
- The UK and Ireland provide information on individual cellular mobile and PPDR TETRA sites which can be accessed via an on-line mapping interface

Usage data can also be provided by monitoring of the radio spectrum. This monitoring can either be routine monitoring for specific frequency bands, or dedicated monitoring when interference is reported to the spectrum agency:

- Routine monitoring is performed in some countries such as Cyprus where usage data also comes from technical measurements (i.e. monitoring stations, on-site technical visits) in order to extract occupancy reports, statistical and analysis reports, and calculation reports.
- Monitoring of the most congested bands can be performed on a regular basis (e.g. Finland).
- Many countries perform monitoring only when interference is alleged to have occurred (e.g. Sweden).
- The Netherlands publishes an annual report on the “state of the ether” which includes graphical usage data for some mobile and licence exempt bands, based on intensive monitoring across the country.

Information on usage differs a lot according to the application involved:

- Broadcast
    - The Geneva 06 plan is applied by all European countries (though the extent of actual deployment of multiplexes varies considerably).
    - L-band 1452-1492 MHz is not used.
    - T-DAB is only deployed in the United Kingdom, Ireland, Denmark and Belgium, but significant take-up has only occurred in the UK.
    - Band III: there is limited harmonisation regarding the use of the VHF band which is either used for TV or digital radio or PMR (and wireless microphones). A number of countries are planning to use Band III for DTT and this may increase in the wake of the decision at WRC-12 regarding 694-790 MHz.

18 See http://www.mastedatabasen.dk/VisKort/PageMap.aspx.

- 2025–2110 MHz and 2200–2290 MHz is being used by MMDS in Lithuania.
- 2600-2690 MHz is being used by MMDS in Ireland.

- Cellular
  - ECO Report 3 on licensing of mobile bands gives detailed information on assignment for the 800, 900, 1800, 2100 and 2600 MHz bands. The 3400-3600 MHz band has been included in the latest survey.
  - The TDD portion (1900-1920/1925 MHz and 2010-2025 MHz) is only used in a limited number of countries and in one instance (Czech Republic), the closure of this service has recently been announced.
  - In some countries (e.g. Cyprus, Ireland), parts of the 900/1800/2100 MHz bands are not yet allocated.
  - There are a limited number of CDMA 450 networks in Eastern and Nordic countries. They are likely to be replaced by LTE networks.
- Fixed links usage is available for many countries in ECO report 173. Even though some information is missing for some countries, it gives specific information on the number of links for each frequency band.
- FWA: the 3.4-3.6 GHz band has a very limited number of users as the WiMAX ecosystem did not develop in Europe. Ficora (Finland) considers that the 3.4-3.6 GHz frequency band is relatively inefficiently used.
- PMR data is difficult to gather given the huge number of authorizations for very small networks (even 10,000 networks in Lithuania). Most countries do not provide detailed assignments and usage data.
- PMSE: usage information is difficult to gather given the sometimes unlicensed status of the associated applications.
- Radars - Aeronautical: many databases exist such as SAFIRE database from Eurocontrol, radionavigation and communications database from ICAO. Databases also exist for radars but there are confidentiality problems due to sharing of the bands with the Defence sector. There is extensive information on the deployment of radars in the 2.7 – 2.9 GHz band (S-band) in a 2010 Radio Spectrum Committee working document detailing the responses to a questionnaire on this band.[19]
- Science
  - Information on meteorology is available from Eumetsat. ESA uses some frequency bands for telecommunications purposes.

19 RSCOM10-44, September 2010.

  - CRAF (Committee on Radio Astronomy Frequencies) oversees radio astronomy spectrum usage at European level.

- SRDs: ERC/Rec.70-03 gives detailed information for each Member State on the conditions of use for SRDs. The implementation status details for each country the status of each frequency band and each type of device. Actual usage data is much more limited due to the licence exempt status.

- Satellite: information on usage also comes from the operators (Inmarsat, SES…)

  - The S-Band (1980–2010 and 2170–2200 MHz) is not used in most European countries. Solaris has only applied for a terrestrial licence in Italy.

  - C-Band. Earth-stations in the C-band are still operating for receive-only means by users such as embassies or enterprises in Europe (e.g. 3 in Lithuania). In Spain, the receive-stations are used in order to get the TV signal from Latin American channels broadcasted in the C-band. In Finland, receive-only cannot be registered and thus the SMA cannot identify usage. Feeder links (largest stations: 6 or 7 in Europe) in C Band: 3550-3700 MHz DL and 6425-6575 MHz UL.

  - Inmarsat highlights the fact that satellites are being built before spectrum is marked as used in EFIS.

3.3.3 Consistency of data

The EFIS database managed by the ECO in Copenhagen provides a valuable information resource on frequency allocations, radio communication applications, rights of use and a broad range of other data including technical interface standards and licensing requirements. Much of this information is relevant and useful for the spectrum inventory and considerable time has been invested by the study team in extracting and analysing the data within EFIS in order to populate the prototype inventory database.

Consistency between CEPT/EFIS and national information sources is good as spectrum agencies generally upload parts of their own databases to fill in the necessary fields in EFIS.

CEPT carries out regular surveys among its members and publishes some reports on spectrum usage, including:

- CEPT periodical reports: report #3 for cellular and FWA,

- CEPT non-periodical reports: report #173 for fixed links.

There are cases where national administrations are not able to identify usage of a dedicated frequency band:

- Satellite receive stations: in the upper part of the C-Band, there are cases where there is no licence attached to reception.
- Scientific use: receive-only stations for meteorology and space exploration.
- MSS: Inmarsat and other mobile satellite service terminals usage cannot be identified, as they can operate across Europe without specific notification to the national spectrum management authority.

EFIS has two key limitations with regard to assessment of spectrum efficiency. Firstly, there is only limited information relating to actual use of spectrum, i.e. whilst a band may be designated as being available for specified applications, there is often no indication of whether the band is actually being used by these applications. We do note, however, that an increasing amount of information on rights of use is being added to EFIS. This will go some way to addressing this issue, albeit for a limited range of applications.

The second issue is that there is some inconsistency in the scope and level of detail of the information provided by individual SMAs. This is illustrated in Table 3, which shows the presence or absence of information within EFIS for a range of applications.[20]

Table 3: Availability of information on various applications in EFIS in the frequency range 400 MHz to 6 GHz

	AT	BE	BG	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SV	ES	SE	UK
Aeronautical	✘	✔	✔	✔	✔	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Broadcasting	✔	✔	✔	✔	✔	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Defence	✔	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✘	✘	✔	✔	✔	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔
Fixed Service	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Meteorology	✘	✔	✘	✔	✔	✔	✔	✔	✘	✔	✔	✔	✔	✘	✔	✔	✘	✔	✔	✔	✔	✔	✘	✔	✔	✔	✘
PMR	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
PMSE	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
PPDR	✔	✔	✔	✔	✔	✘	✔	✔	✘	✔	✔	✔	✘	✔	✔	✘	✔	✘	✘	✔	✔	✔	✔	✔	✘	✘	✘
Radioastronomy	✘	✔	✘	✔	✔	✔	✘	✔	✘	✔	✔	✔	✔	✘	✘	✘	✘	✘	✔	✔	✘	✔	✔	✔	✔	✔	✘
SRDs	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

The level of detail provided also varies significantly among countries, particularly with regard to more detailed information such as interface standards and rights of use. Whilst there is clear merit in using the existing EFIS process to gather any additional information relating to spectrum usage, consideration may need to be given to how to ensure greater consistency in the information provided to enable reliable assessment and comparison of efficiency to be made.

20 As noted previously, in some cases different terminology is used in EFIS, e.g. PPDR may be referred to as “Emergency Services” and PMSE as “SAB / SAP. Where information is contained in EFIS relating to any of these alternative application terms this is included in the table.

3.3.4 Confidentiality issues

Confidentiality issues appeared during the interview phase. Sensitive information exists both for governmental and for commercial applications. Detailed information on cellular sites proves to be sensitive in France, for instance. Other concerns mentioned by interviewees were the following:

- Denmark: ERST provided the number of FWA subscribers but asked that this information be treated as confidential.
- France: ANFr provided detailed usage status for ARCEP and research (science) but asked that this information remain confidential.
- Radars: a database is operated by ICAO, but there are confidentiality problems due to sharing of the base with the Defence sector.

3.3.5 Availability of quantitative data

Quantitative data on spectrum use proved particularly difficult to find for most services. Where information is available, it typically relates to the number of licences issued or (in the case of TV broadcasting or public mobile networks), the extent of national coverage available. The graphic below provides examples of quantitative data that is available and that can be used to make a judgement on the relative extent to which spectrum is being used.

Table 4: Examples of availability of quantitative data

Frequency		Parameter	Availability of Quantitative Data																										
F1	F2		AT	BE	BG	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SV	ES	SE	UK
401	406	Meteorological deployments								✓	✓	✓					✓						✓	✓					✓
406.1	470	PMR licences			✓	✓		✓	✓	✓		✓	✓	✓				✓	✓		✓	✓	✓	✓			✓		✓
406.1	470	PMR users (mobiles)								✓			✓	✓			✓	✓	✓								✓		
470	790	DTT multiplexes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
880	915	GSM population coverage			✓	✓	✓	✓	✓									✓	✓	✓		✓		✓				✓	✓
880	915	GSM geographic coverage			✓	✓		✓										✓	✓			✓		✓				✓	
1215	1400	No. of aeronautical radars			✓			✓						✓								✓							
1350	1375	No. of fixed Links	✓			✓				✓	✓				✓			✓	✓			✓		✓		✓	✓	✓	✓
1920	1980	UMTS/HSPA pop coverage			✓	✓	✓	✓			✓								✓			✓		✓				✓	
1920	1980	UMTS/HSPA geog coverage			✓	✓					✓								✓	✓		✓		✓				✓	
2700	2900	No. of aeronautical radars	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
3400	3600	No. of BWA licences	✓	✓	✓		✓	✓	✓	✓	✓					✓	✓	✓	✓	✓				✓	✓		✓	✓	✓
3800	4200	No. of fixed links			✓					✓		✓		✓				✓		✓				✓		✓			✓
3800	4200	No. of satellite earth stations	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
5470	5650	No. of Weather radars	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
5925	6425	No. of fixed links	✓		✓	✓	✓			✓	✓		✓	✓	✓		✓	✓	✓	✓		✓	✓	✓		✓		✓	✓
5925	6425	No. of satellite earth stations			✓	✓		✓		✓		✓	✓						✓			✓	✓	✓		✓			

4 Defining and assessing the efficiency of spectrum use

This section considers in depth how to define and assess the efficiency of spectrum use. Section 4.1 provides an introduction to our overall methodology. Section 4.2 describes our specific criteria for *technical* efficiency. Section 4.3 explains how we apply the technical criteria in practice. Section 4.4 explains our approach to sharing, which could be viewed as an element of efficiency but is intertwined with utilisation. Section 4.5 discusses monitoring of spectrum utilisation. With Sections 4.6 and 4.7, we move from the technical to the socio-economic, first considering criteria and then discussing how to apply them to specific proposed policy interventions.

4.1 Introduction

In laying out general principles, it is useful to distinguish between those that relate to efficiency metrics (Section 4.1.1), and those that relate the process of applying them (Section 4.1.2).

4.1.1 General considerations for metrics of efficiency

Earlier in this Report, Section 2.2 introduced a few general considerations and guidelines for metrics of efficiency:

- It is important to avoid over-simplifications.
    - Any metric must be understood in context.
    - No single metric is likely to be definitive; rather, multiple metrics should be considered holistically.
- Transparent and repeatable process is important.
    - Quantitative metrics are useful, but in practice qualitative metrics will surely also be required.
    - It is crucial that metrics be, insofar as possible, objective and verifiable.
- Metrics that seek to measure a possible lack of efficiency should avoid contamination with the proposed solution; otherwise, the analysis becomes complex and possibly circular. Efficiency should be assessed on its own merits.

There are potentially many metrics associated with technical, economic and social efficiency. In order to keep the problem manageable, it is necessary to approach it in a systematic way. Notably, we consider it essential to distinguish among:

- Metrics that relate to the application (which may be present in more than one band)

- Metrics that relate to the band (which may support more than one application)
- Metrics that relate to possible measures that might be taken to address inefficiencies in the band

Suppose the analyst were considering measures to address a perceived inefficiency through an *Impact Assessment*. The first two of these categories are part of the *problem definition*, and inevitably interact. For example, the amount of spectrum and the frequencies chosen affect both the value of the application, and the cost of building out the infrastructure to deliver the application. They interact with the measures that could be taken to address the inefficiencies, to be sure, but they are not necessarily the metrics that are most relevant to addressing inefficiencies.

Metrics that relate to possible measures that might be taken to address inefficiencies in a band are associated with the Options of the Impact Assessment, and with the analysis of the impacts that flow from each of the Options. They are not intrinsic to the situation on the ground (or rather, in the air) at the time of the analysis, but rather are option-dependent. In other words, they are not linked exclusively to the *problem*, but also to potential *solutions*.

Once again, it is important to distinguish clearly between metrics associated with the *problem*, and those that flow from the possible *solutions*; otherwise, the analysis becomes hopelessly complex, and possibly circular.

In this key respect, our work goes considerably beyond that of the joint BEREC/RSPG draft report on exploring the economic and social value of radio spectrum (RSPG 12-410 final).

4.1.2 General considerations for identifying candidate bands for improvement

Quantitative and qualitative measures of technical efficiency, where available, can be abstracted into four levels (not in use or not applicable [0], low [1], medium [2], and high [3]). Where meaningful quantitative data is not available or appropriate, qualitative measures can be abstracted into the same four levels. Colours can then be associated with each level, and graphic tools can help the human analyst to look for clusters, patterns and trends. Consider, for example, Table 5.

Table 5: Colour coding of an efficiency metric

F1	F2		AT	BE	BG	CY	CZ	DK	EE	FI	FR	DE
863	870		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
880	890		71%	79%	79%	21%	71%	79%	79%	79%	71%	79%
890	915		71%	79%	79%	71%	71%	79%	79%	79%	71%	79%

Economic indicators will seek to identify the incremental economic value of spectrum in a band and geography, and also to help a human analyst to evaluate costs and benefits of a proposed change to spectrum use in a given band or geography. As with technical efficiency, we advocate reducing economic measures to a scale of relative efficiency.

Social indicators will seek to measure the incremental impact use of a band contributes to achieving social objectives at European level. Often, these measures are not known, or are not quantifiable; furthermore, it is often the case that changes in spectrum use do not affect the delivery of the socially valued output, but rather impact on the costs of its delivery. For this reason, we have opted for an approach more closely linked to the way the spectrum is used rather than the social output it supports; in other words, we consider the costs and benefits of a proposed policy intervention, rather than the intrinsic value of the application itself (which does not necessarily change as a result of the policy intervention).

We have sought to develop normalized measures that can reasonably be compared across countries and bands. This is not easy! There are no published precedents for devising technical and economic and social efficiency metrics for the full range of bands and applications that will be considered by the inventory.[21] Determining the degree to which this is possible is itself a useful finding from this study.

These metrics were presented at the First and Final Workshops for this project, and comments were received from stakeholders. Most attendees appeared to be comfortable with the indicators. In any case, different indicators could be computed from our data (or from other data) at a later date if desired.

Note, too, that the rating of a band in terms of its technical, economic and social efficiency will tend to change over time, not only because usage of the band or geography in question changes, but also due to changes in the technological frontier as to what is achievable and due to changes in policy priorities that affect what is regarded as socially desirable. This would seem to imply that the Spectrum Inventory needs to be thought of as a time series, rather than a static view or a snapshot.

If the technical efficiency of a band or application is negligible or zero (e.g. there is negligible use of a band now, or anticipated in future) then economic and social efficiency are also zero, and it is very clear that there is a problem that needs to be addressed.

Low utilisation of a band is often indicative of low efficiency and/or low perceived value of the associated service, but not always. Disaster relief communications or military exercises could have spectrum utilization that varies enormously based on the exigencies of the moment, and in each case the value of spectrum used in this way may be very high. Intermittent use may signal the scope to improve efficiency through

21 For example, the activities being undertaken in the US by the NTIA to improve the efficiency of use of spectrum allocated to government are predicated on the assumption that there is no change in the delivery of services or outputs by government entities. See Annex 3.

sharing, though this will depend on the predictability of the intermittent use. In other words, the presence or absence of traffic in a given band and geography cannot be the only measure of the degree to which the band is being utilised.

Conversely, while moderate or high technical efficiency is desirable, high technical efficiency does not preclude the existence of an alternative use for the band that has much higher economic and/or social value.

A possible decision rule to identify potential problem bands as priorities for further investigation would be as follows:

- Identify bands whose technical efficiency falls below a predefined threshold and/or where for commercial services there are other much higher value applications that might use the band. (The application of this threshold must consider the variation in technical efficiency across Member States.)
- Consider whether plausible policy interventions could raise the technical and/or economic efficiency of low efficiency bands.
- Where low technical efficiency, together with economic indicators, might suggest low perceived or actual value of the use of spectrum by applications in the band, consider whether the current spectrum allocations are warranted going forward.

The interrelated nature of spectrum use – a change in the allocated use in one band may increase/reduce use of/demand for other bands – means that options for addressing specific “problem” bands may need to consider a wider set of bands for change.

4.2 Our methodology for assessing technical efficiency

One of the key objectives of the study is to develop an appropriate methodology for defining and assessing the efficiency of spectrum use and to find an appropriate balance between technical and economic efficiency of existing spectrum uses. The terms of reference refer to technical efficiency in terms of the relative spectral efficiency of the various technologies and approaches to delivering services, unused spectrum, or opportunities to use spectrum more efficiently.

During the course of the study, it became evident that no clear definition of technical spectral efficiency exists that can be applied to all services. The ITU has attempted to define efficiency as a function of the “useful effect obtained with the aid of the communication system in question” and a spectrum utilisation factor comprising bandwidth, space and time; however, this approach depends on access to quantifiable data, which is often unavailable. Moreover, the reference to “useful effect” implies economic as well as technical considerations. Even where suitable data does exist, such as the density of traffic carried across a cellular mobile network, care must be taken in interpreting such data and in making comparisons between different countries or different frequency bands. For example, traffic density is largely a function of population density, so efficiency judged by this measure is always likely to appear greatest in densely populated urban areas; however, using advanced technology to deliver wireless broadband to more remote areas also represents efficient use, and any efficiency comparison should be able to take account of such differing scenarios.

Applications such as cellular mobile, private mobile radio, broadcasting and point-to-point links are fundamentally different from one another in the way in which they use spectrum, e.g. in terms of radiated power, frequency re-use, antenna directivity and the nature of the service being delivered. It is therefore not possible to define specific efficiency parameters that can be compared across all services. It is, however, possible to compare the relative spectrum efficiency in bands that are used by the same or similar radio services, such as within the fourteen application groupings that we defined in Section 3.3.1, against “best practice” benchmarks based on the information gathered during the study.

To facilitate comparison across different application groupings, four generic efficiency criteria were identified that can be applied consistently to all applications and frequency bands, namely:

1. **Utilisation:** a measure of how much of the available spectrum resource is currently being used and for how much of the time, by each of the applications using a particular band.

2. **Demand Trend**: an indicator of whether the current level of demand for a particular application is stable or likely to change significantly in the future. This takes account, for example, of bands that have recently been licensed but not yet brought into use, but where high usage is anticipated once the service has been launched.[22]

3. **Technology**: an indicator of the relative spectrum efficiency of the technologies deployed, compared to state of the art benchmarks for the application(s) concerned.

4. **Geographic Extent**: An indication of the population or geographic coverage provided (in the case of networks serving the public), or the extent of the national territory where the spectrum resource is being used (for other applications).

Rankings were applied to each of these four criteria on an intentionally coarse 0-3 scale (e.g. no usage, low usage, medium usage, or high usage). Quantitative, objective data were used wherever it was available (e.g. number of licences or equipment deployments); otherwise, objective qualitative measures were used.

22 The demand trend could be viewed as a dynamic, rather than a static, view of utilisation.

An overall relative technical efficiency indicator was derived by combining the four individual criteria ratings and determining percentile values for each frequency band in each country, with the highest and lowest percentiles corresponding to the highest and lowest values of the overall efficiency indicator. Since a key purpose of the analysis is to identify bands where there is clear evidence of under-utilisation (and hence potential scope for improvement), and given that the relative importance of each of the four criteria is likely to vary somewhat by frequency band, we decided not to apply weightings to the criteria when deriving the overall efficiency indicator.

As noted in Section 4.1.1, in an ideal world, these indicators would go through some public consultation process. For the current pilot study, this is impractical, but little is lost since different indicators could presumably be computed from our data (or from other data) at a later date if desired.

Note, too, that the technical efficiency indicator values will tend to change over time, not only because usage of the band or geography in question changes, but also due to changes in the technological frontier as to what is achievable. This would seem to imply that the Spectrum Inventory needs to be thought of as a time series, rather than a static view or a snapshot.

Once the percentiles have been computed, the values can be displayed graphically using a graduated colour scale (e.g. red-yellow-green) to facilitate identification of colour clusters that might suggest a band or geography worthy of attention.

In interpreting indicators and metrics, it is important to be sensitive to the specifics of the situation. For example, high utilisation of a band is often indicative of high efficiency and/or high perceived value of the associated service, but the converse may or may not be true. For a radio astronomy band, low utilisation in terms of transmission is the expected state of affairs; however, for our efficiency analysis we have assumed utilisation includes reception (e.g. of extra-terrestrial signals) and have rated the utilisation criterion accordingly. We have made analogous adjustments for bands used for disaster relief or military exercises, where utilisation could vary greatly depending on the presence or absence of a disaster or of military exercises.

4.3 Applying Benchmarks to the Technical Efficiency Criteria

In order to rate the individual efficiency criteria for each band, it is necessary to define appropriate benchmarks relevant to the application(s) concerned. Benchmarks ideally should be application-specific to reflect the different characteristics of each application grouping; however, this depends on availability of sufficiently detailed information across the majority of Member States, which is often not the case. In many cases, we have therefore needed to make a qualitative assessment based on generic benchmarks. Our objective is to compare relative usage of individual bands across the

EU, and the benchmarks we have developed are intended to reflect this by enabling a comparison to be made against the identified highest ranking countries where possible.

Specific and generic benchmarks for each of the four criteria are discussed in the remainder of this Section of the report.

4.3.1 Utilisation criteria

Technical criteria as regards utilisation appear in Table 6.

Table 6: Technical criteria for utilisation

Rating	**0**	**1**	**2**	**3**
Generic Benchmark	Not used	Lightly used	Moderate use	Heavily used
Cellular bands-mature *Percentage of band in use*	<30%	30-60%	60-90%	>90%
Cellular bands-new*	Not in use	Licences issued but not launched	Services launched in part of band	Services launched in entire band
DTT band	No DTT	1-3 national multiplexes	4-5 national multiplexes	>5 national multiplexes
Fixed Link band	Not used	<1 link per million pop (but not zero)	1-10 per million pop.	>10 links per million pop.

* i.e. band made available in last 5 years

4.3.2 Demand trend criteria

A common rating scale is applied to all applications for demand growth, namely:

- 0: Demand declining
- 1: Demand stable
- 2: Low or moderate demand growth
- 3: High demand growth

4.3.3 Technology criteria

Technology is largely application-dependent, particularly in harmonised frequency bands where international standards have been developed (such as GSM, IMT and DVB-T). In general, the technologies deployed in a particular band should be benchmarked against the standard that represents the current state of the art in spectrum efficiency terms. For example, in the case of cellular mobile, this would be the LTE standard (or an equivalent such as WiMAX), and for TV broadcasting the DVB-T2 standard would be appropriate. The technology benchmarks will of course change over time as new, more efficient standards emerge.

The specific and generic technology benchmarks used in the analysis are shown in Table 7.

Table 7: Technical criteria for technology

Rating	0	1	2	3
Cellular mobile bands	GSM only (or equivalent)	GSM EDGE	Mix of LTE/HSPA and GSM	All LTE/HSPA or equivalent
Digital Television	MPEG2 only	MPEG4 and MPEG2	All MPEG4 or at least 1 DVB-T2	All MPEG4 and at least 1 DVB-T2
Fixed link bands	Exclusively analogue	Mostly analogue, some digital	Mostly digital, some analogue	Exclusively digital
PMR bands	Exclusively analogue, all 25 kHz channels	Exclusively analogue, mostly 12.5 kHz channels	Exclusively analogue, all 12.5 kHz channels	Substantial migration to digital (>25%)
Generic Benchmark	All use based on legacy standards	Most use based on legacy standards	Most use compliant with latest standards	All use compliant with latest standards

4.3.4 Geographic criteria

Ideally, the geographic criterion rating for broadcast or public mobile networks should be based on actual coverage levels (population or geographic), however such specific data is available only for a limited number of countries. Where information is available, the rating is based on the following values, which reflect the range of coverage values across the EU for the application concerned.

Table 8: Technical criteria for geographic coverage

Rating	0	1	2	3
Cellular bands – mature ***Population coverage***	<80% for all networks	≥80% for at least 1 nwk	≥80% for all networks	>90% for all networks
Cellular bands – new ***Population coverage***	Not yet launched	<50%	50-75%	>75%
DTT band ***Population coverage***	<90% for all muxes	>90% for at least 1 mux	>90% for at least 2 muxes	>90% for all muxes

For other applications, the criterion rating can be based on the number of distinct geographic locations where the spectrum is deployed, in accordance with the following benchmarks:

- 0: No deployment currently
- 1: Deployment at a single location only
- 2: Deployment at multiple locations, but limited to part of the national territory
- 3: Deployment at multiple locations throughout the national territory

Note that the reference to a single location corresponds to a single link in the case of point-to-point fixed links and a single base station in the case of PMR.

4.4 Taking account of band sharing in the technical efficiency analysis

One way in which spectrum efficiency can be improved is by increasing the extent of sharing between different applications or services, where this is feasible. Indeed, the study terms of reference explicitly refer to identifying spectrum sharing opportunities. As part of our technical efficiency analysis we initially included a fifth criterion based on the degree of sharing in each band, in accordance with Table 9.

Table 9: Band sharing

Rating	0	1	2	3
Generic Benchmark	No sharing	Limited sharing between 2 applications or user types	Widespread sharing between 2 applications or user types OR limited sharing between 3 or more	Widespread sharing between 3 or more applications or user types

Concerns were raised at the public workshop that this approach might be misleading in that some very heavily used bands might appear less efficiently used than in fact they are by virtue of the fact that no sharing takes place, when in fact the lack of sharing is itself a consequence of the existing very heavy usage. A single application already makes efficient use of such a band. It was also argued that the impact of sharing was already accounted for in the usage criterion, in that this related to the total usage in each band by all applications. In other words, there was a risk of double-counting the importance of utilisation of the band.

We considered an alternative approach that would take account of both the *actual* sharing taking place in each band and the *potential* for sharing, taking account of the technical characteristics and level of usage of existing applications. The rating applied would then be based the difference between the two, i.e. a band where there was considered to be a high potential for sharing but none taking place would receive the minimum rating, whereas a band where full use was already being made of the sharing potential would receive the maximum rating (3). The potential for sharing could be assessed at a high level by considering the extent to which sharing already takes place between the fourteen identified application groupings of the application(s) currently using each band, but this would require a degree of judgement and would not necessarily capture opportunities for future sharing, e.g. by making use of new technologies such as cognitive radio. Furthermore, development of sharing criteria is a complex process that in practice is likely to required detailed band by band analysis, taking account of the technical parameters of the applications concerned.

We therefore decided not to include sharing as a specific criterion in assessing the efficiency in each band, but to retain sharing as a stand-alone criterion to identify bands where extensive sharing does already take place, or where there *may* be scope for further sharing to be considered in the future, subject to the development of appropriate sharing criteria.

4.5 Technical measurements

The study terms of reference require us to “develop a methodology for deciding in which cases technical measurements are necessary to be able to assess and/or validate the efficiency of spectrum use in a specific band” and to “design a mechanism for undertaking such measurements, where they are needed”. Any related costs associated with such measurements should also be estimated.

The value of technical measurements as a tool for measuring or verifying efficient spectrum use depends very much on how the spectrum is being used. For example, measurements can provide an effective means to ascertain the coverage provided by mobile or broadcast networks, ensuring that licence conditions are met and the economic and social benefits associated with improved coverage are achieved.

Measurements can also be used to compare the quality of service provided by mobile networks, although care needs to be taken in interpreting such data (e.g. ensuring that factors such as the time of day are taken into account).

We have also found examples of monitoring being used to assess the occupancy of licence exempt spectrum, where other usage indicators such as the number of licences or terminals in circulation do not exist. The Netherlands has used this approach to highlight differences in the extent of use of the 2.4 GHz and 5 GHz WiFi bands and the 863-870 MHz short range devices band;[23] however, even here, care must be taken in interpreting the results, since low power transmissions such as these may not always be detected if they are very localised or operating in indoor environments, for example.

For other applications, measurements are likely to be of less benefit in assessing the extent of use. For example, applications like Defence, PPDR and PMSE require access to spectrum on an occasional and often unpredictable basis, corresponding to specific events or incidents. Spectrum demand at such times may be very high (but limited to specific locations) and the "background" utilisation may be very low. In other cases, such as the GNSS bands, low signal levels requiring specialised receiving equipment are the norm, and are unlikely to be detected by spectrum monitoring facilities. Technical measurements are unlikely to provide a useful indicator of spectrum demand in such cases, although careful monitoring of usage patterns, e.g. through an effective logging and reporting process, may be helpful in identifying demand peaks by time and location, which could be helpful in planning future spectrum sharing arrangements.

It should also be noted that undertaking measurements over wide frequency ranges and wide geographic areas is particularly challenging due to the highly dynamic nature of radio signal propagation and the difficulty of configuring antennas to give reliable gain and directivity characteristics over a large band. Results for some types of services can be prone to misinterpretation. For example, swept frequency measurements may fail to detect pulsed transmissions such as radar systems if the pulse does not coincide with the precise time at which the measuring equipment is tuned to the relevant frequency, thus falsely indicating the frequency as unused when in fact it is in continuous use by a pulsed radar system playing a critical role in aeronautical or maritime safety. Detecting emissions from highly directional antennas, such as point-to-point links or satellite earth stations, is also challenging.

Perhaps the greatest benefit derived from spectrum monitoring is the ability to verify licensing records and identify illegal transmissions, and this is certainly the most common application of monitoring in EU member states, many of whom have reported regular detection of illegal broadcasters, non-compliant wireless devices or illegal jammers as a result of their monitoring activities

23 Examples of measurement results can be found in the Agentschap Teleocm annual report "Staat van de Ether".

4.5.1 Availability and suitability of current measurements of national SMAs

Our discussions with SMAs have indicated that all have the capability to undertake technical measurements, but that in the majority of cases these are used exclusively for the purposes of managing interference rather than monitoring the intensity or efficiency of spectrum use. Typically, measurement capabilities include one or more fixed permanent monitoring sites, supplemented by a small number of remote (unmanned) fixed sites and mobile monitoring vehicles. Most monitoring activities are undertaken in response to interference complaints, but in some cases monitoring has been carried out to support planned re-farming activities (e.g. by clarifying the potential impact of new services on existing services in adjacent bands or vice versa).

It is also worth noting that the increasing proliferation of smartphones and other mobile broadband devices has led to increasing use of user-initiated monitoring of mobile network coverage and quality of service. For example, the UK SMA Ofcom has undertaken monitoring of mobile broadband network performance in conjunction with broadband QoS specialists Epitiro which involved a 1,000 strong consumer panel using an installed PC application to generate statistical data on network speeds across the UK.[24] Hence, in some cases, technical data on spectrum usage can be gathered without the need for significant investment or effort on the part of the SMA, but using instead data sourced directly from end-user devices.

Table 10 demonstrates that monitoring use and capability vary great among the Member States. Whilst all of the countries who provided information use monitoring in response to interference cases, routine monitoring (e.g. to assess usage of particular bands, verify coverage or detect illegal use) is less common. Typically, NRAs use a mix of manned stations, remote controlled stations and mobile stations (vehicles) to carry out their monitoring activities.

Table 10: Use of monitoring in the EU

	AT	BE	CY	CZ	DK	EE	FI	FR	DE	HU	IE	LT	LU	NL	PL	PT	SV	ES	SE	UK
Routine monitoring	✓	✓	✓	✓	✗	✓	✓	✗	✗	✓	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓
Interference monitoring	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fixed stations	7	1	0	2		1	1	1	7	1			1	1	13	4	2	55		
Remote stations	51	15	4	10		9	4	59	80	31			0	13	9	16	7	61		
Mobile stations	34	2	2	18		4	3	26		13	1		1	31	17	6	4	17		
Annual cost €M		0.5	1.0	0.6		0.03	1.0	20.0				0.4		1.8		6.4	1.0			

Reported costs of monitoring vary significantly, but this is because some NRAs do not include costs such as equipment procurement and maintenance, which can account for a significant element of total costs. The Netherlands, which has one of the most developed facilities for both routine and interference monitoring, estimated the total

24 See http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/broadband-speeds/main/mobile-bb-10.

annual cost to be €1.75M, which includes hardware and software costs. Operational (staffing) costs were estimated to be equivalent to approximately 3 full time staff. However, these costs relate only to the recently commissioned “next generation” system that is used for routine monitoring. The cost of other monitoring activities is included within the NRA’s hourly rates and not explicitly available. In Estonia, the cost estimate includes labour, fuel, insurance, facilities management and measuring equipment maintenance / calibration, but excludes the amortisation cost of monitoring equipment and software. The much higher estimate for France includes capital investments, operating expenses and salaries.

Where routine monitoring is deployed, this is typically either to detect illegal use of spectrum or to clarify spectrum usage where re-farming is planned or new services are to be introduced.

4.5.2 Relevance of monitoring to the spectrum inventory

Feedback from a number of NRAs indicates that routine monitoring of spectrum can be beneficial so long as this is targeted towards particular bands or applications where spectrum use is a concern. This may include bands where there is a prevalence of illegal or non-compliant use or bands that have been identified for possible alternative uses but where the current level of use is not known. For example, a number of SMAs have undertaken measurements in relation to the introduction of mobile services in the digital dividend band (800 MHz) and the 2.6 GHz band. These measurements have focussed on the potential levels of interference that might arise to or from services operating in adjacent bands (digital TV at 800 MHz and aeronautical radars at 2.6 GHz) and have been used to develop appropriate remediation measures to minimise the likelihood of interference arising from deployment of the new service.[25]

Monitoring can also assist the inventory process by cross-checking the validity of licensing data (i.e. ensuring that historic assignments are still active).

Some SMAs (notably Finland and the UK) have also undertaken research including technical measurements relating to cognitive radio deployment in the “white space” frequencies within the UHF broadcast band. It is likely that such measurements will play an important future role in implementing any second digital dividend band.

Finally, routine monitoring of licence exempt bands, which has been undertaken in the Netherlands and the UK, can provide a useful insight into the level of demand for such spectrum which would be difficult to obtain by other means. The limitations of measurements, e.g. to detect low power or indoor transmissions, should be taken into account when interpreting the results of such activities, however.

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25 See for example Ofcom’s Digital Dividend Review (http://stakeholders.ofcom.org.uk/spectrum/project-pages/ddr/) and the BIPT / Intersoft report on interference to S-band radars (www.ibpt.be/GetDocument.aspx?forObjectID=3527&lang=en).

All things considered, our feeling is that monitoring is likely to be of greater value for assessing the costs and benefits of a specific policy intervention (i.e. the second of the two phases that we envision in the process) rather than for identifying bands and applications where technical efficiency could be improved. We nonetheless applaud those Member States where monitoring is routine, inasmuch as they provide a valuable analytical baseline that would not otherwise exist.

4.6 Indicators of socio-economic efficiency

The socio-economic efficiency of spectrum use matters because high (or low) technical efficiency does not necessarily imply that the current use of a band yields high (or low) benefits for consumers and society as a whole. Our terms of reference ask us to develop a methodology for defining and assessing "the overall economic efficiency of existing use, and the social efficiency of spectrum use (meeting public service objectives, the level of benefit to the citizen, society and the environment)".

In this section, we deal with metrics of economic efficiency and of social efficiency of a specific application (which may use more than one band), or of a specific band (which may have more than one application active). A relative valuation of the economic and social benefits from using bands for different applications is required to inform any assessment of whether the economic and social value to society from the band may be enhanced by changing regulation to allow/facilitate new uses (either on a shared or exclusive basis). Because most applications use more than a single frequency band, the value of a particular band to a given application is not the average value of spectrum to that application but is the *incremental* value of the band under consideration. The incremental changes being contemplated are necessarily hypothetical (i.e. have not already been implemented) and so measures of value should ideally be estimated based on forecasts for the situation being considered. This will be the case in the second Phase of the analysis where bands identified for changes in allocations are investigated in more detail. However, for the initial identification of these bands we need "order of magnitude" estimates of the incremental value of spectrum for different bands and applications based on existing information and data.

The following subsections elaborate on:

- Measures of the economic and social value of spectrum
- The relative economic and social value of applications in various bands

Supporting information is given in Annex 1. Metrics relevant to options to change a band or application are dealt with in Section 4.7.

4.6.1 Measures of the economic and social efficiency

Economists measure economic and social efficiency by the sum of:

- **Economic welfare:** This equals private benefits to consumers and producers from an activity. The consumer benefit (or surplus) from an application is the difference between what consumers are willing to pay and the price they actually pay for an application. The producer benefit is the profit (or surplus) earned over and above all costs including the cost of capital to the business.

- **Social welfare:** This equals the external benefits or costs of an activity, i.e. the benefits or costs that that are external to private benefits. These benefits or costs are not internalised through payments between affected parties and include impacts such as air or noise pollution, a change in safety of life risks and changes in psychic well-being.

Other economic indicators, such as revenues, GDP and employment, are generally incomplete in the sense they omit elements of private and social impacts and in some cases can be highly misleading. For example, while there may publicly data available for the revenues, GDP or employment associated with spectrum using applications (e.g. aeronautical, maritime, mobile, or broadcasting), these data are not usually linked to the use of particular frequency bands. This linkage depends on how the spectrum assigned affects the provision of final services – for example, the allocation of 2.7 - 2.9 GHz to the aeronautical service has little if any impact on the provision of aeronautical services in Sweden (where there is little use of the band), but it has a significant impact on the provision of these services in the UK (where the scale of commercial aeronautical services at busy airports would have to be reduced significantly if the band were not available for use by primary radars[26]).

- Economic welfare (i.e. private benefits) is inherently easier to value than social welfare (i.e. external benefits or costs) because the former relates to market transactions which can potentially be observed. The scale of social impacts is often not well understood (e.g. amount of pollution, gain in feeling secure), nor is their valuation. However, there has been research into the value of some external effects, and examples are shown in Table 11. Other external effects are not well understood at all and are possibly not amenable to quantification. For example, we have not found any literature on the security benefits to citizens of defence expenditures and there are few if any good metrics to assess the benefits of publicly funded scientific research.[27] [28]

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26 We assume safety standards cannot be changed. Hence safe operation of the airspace is only possible with many fewer aircraft.

27 Attempts to measure the economic value of science research have had mixed success. See for example, "What is science really worth", Nature, Vol 465, 10 June 2010 http://www.nature.com/news/2010/100609/full/465682a.html.

Table 11: Estimates of external value

Impact	Value estimate
"Value of life" (per casualty)	€1,018,200[29] (between €200,000 and €1,650,000 per EU Member State). For air transport, appraisals values of €1-2m are recommended.[30]
Quality adjusted life year	This has been researched at a European level.[31] Value same as UK value of £20-30,000.
Value of greenhouse gas abatement (per tonne CO_2)	2010: €25[32] 2020: €40 2030: €55[33] 2040: €70 2050: €85[34] Base value for air transport is €37[35]
Public service broadcasting	For the UK, private value of the BBC services equals £168/year and social value is another £3/year[36].

The relative economic and social welfare associated with spectrum use may be deduced from opportunity cost values - either estimated values or values observed from auctions and market transactions (e.g. trades). Economic and social welfare and opportunity cost are two quite different measures of economic and social benefit. They are related to one another in that if the opportunity cost (or market price) of spectrum for use A is greater than that for use B, then under some restrictive conditions the economic welfare from use A will be greater than that from use B.

28 The following measures of the impact of Federal science investment put forward by the STAR program in the US: Economic growth (through patents, firm start ups and other measures); Workforce outcomes (through student mobility and employment); Scientific knowledge (such as publications and citations); and social outcomes (such as health and environment). See http://sites.nationalacademies.org/PGA/fdp/PGA_057189.

29 2002 "unit costs per fatality". Cost-benefit assessment and prioritisation of vehicle safety technologies. EC – DG TREN. 2006. P44-47. http://ec.europa.eu/transport/roadsafety_library/publications/vehicle_safety_technologies_final_report.pdf.

30 Values for appraisal of European air transport projects are given in "Standard Inputs for Eurocontrol Cost Benefit Analyses", Edition 5, December 2011, Eurocontrol. http://www.eurocontrol.int/ecosoc/gallery/content/public/documents/CBA%20examples/Standard_Inputs_fin.pdf.

31 http://research.ncl.ac.uk/eurovaq/index.html.

32 2010-2020 values are based on avoidance costs.

33 2030-2050 values are based on damage costs.

34 "Recommended values for the external costs of climate change". Handbook on estimation of external costs in the transport sector. 2008. P264. http://www.europadecentraal.nl/documents/dossiers/Transport/2008_01_15_handbook_external_cost_en.pdf.

35 Values for appraisal of European air transport projects are given in "Standard Inputs for Eurocontrol Cost Benefit Analyses", Edition 5, December 2011, Eurocontrol.

36 Collins, R (2007). Public Value and the BBC: a report prepared for the Work Foundation's public value consortium. http://www.theworkfoundation.com/assets/docs/publications/174_publicvalue_bbc.pdf.

The support for this conclusion comes from economic theory[37] which finds that transactions that are guided by market prices (i.e. the opportunity cost) will result in an optimal allocation of resources (i.e. maximise economic and social welfare) assuming market players are rational, that they have perfect information, and that there are no significant economic externalities[38] associated with resource use after taking account of policy interventions (e.g. taxes/subsidies or regulation).[39] In these circumstances, the fact that use A paid more than use B for a block of spectrum means that that the economic welfare from use A is higher than that from use B. This suggests that market prices and evidence of which services win spectrum in competition with others could be used to provide an ordinal ranking of the value of spectrum in alternative uses in situations where (uncorrected) externalities are not significant.

In practice, externalities associated with the spectrum itself (e.g. harmful interference) are addressed through technical controls and harmonisation measures. Many externalities associated with the use of the spectrum are addressed through government funding and provision of services (e.g. emergency services), subsidies for private services (e.g. rural broadband), and/or regulation (e.g. content controls on broadcasters, competition policy in respect of monopoly); however, this is not always the case. Values such as those reported in Table 11 could be used to quantify impacts. If quantification is not possible, an alternative approach such as that described in section 4.6.3 could be adopted.

Clearly, not all market actors have perfect information, not all market actors are necessarily rational, and in some cases economic externalities may not be addressed through regulation or funding measures. Even in instances where these issues do not pose serious problems, estimating the economic welfare associated with current and potentially alternative uses of spectrum is a major task, and the estimates produced will be subject to some uncertainty. To estimate consumer and producer surplus one needs to make estimates of current and future consumer willingness to pay for the application, prices, quantities consumed, and the difference in service costs between a situation in which the spectrum is available and where it is not (in which case different equipment or different bands may have to be used to delivering service). Bespoke studies are required to perform these estimations. For this study, we have had to make best use of publicly available data that is necessarily imperfect.

In practice, there is partial data for market prices/opportunity cost estimates and welfare estimates – average and incremental. To make the most use of the available information, one would ideally combine the data in some way. In the case where we have linked

37 See "Existence of an Equilibrium for a Competitive Economy", K Arrow and G Debreu, *Econometrica*, Vol 22, No 3, July 1954.

38 External value is value that is not monetised in market transactions. This value may be enjoyed by individuals (e.g. a clean environment, competitive market or a secure society, network benefits) and in addition may be valued by society as a whole and expressed in government policy objectives (e.g. a low carbon economy, informed democracy, universal broadband provision).

39 That is where interventions are in place to correct for the externality then market outcomes should lead to a reasonably efficient allocation of resources.

chains of value for different spectrum bands, this is possible. If for example pa>pb and Wb>Wc, then we can say Wa>Wb>Wc.[40] This means we can derive an ordinal ranking of the value of a band for different applications, but we cannot necessarily deduce anything about the cardinal ranking i.e. the relative magnitude of Wa and Wc.

4.6.2 Estimates of relative economic value

Table 12 shows our best estimates for a relative ranking of the incremental economic value of various applications across bands in the 400 MHz to 6 GHz range, drawing on the data and analysis in Annex 1.

There is data on spectrum value for various (terrestrial and satellite) mobile, broadcasting and PMSE services in a variety of bands. We have not found any market values or economic surplus calculations[41] for spectrum used for defence, transport or science applications. As a minor exception, the opportunity cost based spectrum prices that are sometimes paid by spectrum users in the UK arguably set a floor on the value of the bands where this pricing is applied.

These data are at best indicative because they are fragmentary, they are applied at different times under differing market and technology conditions, and the data give a wide range of values for each application/band combination. Nevertheless, we consider that they could be used to provide an order of magnitude view of the value of allocation of different bands to different applications.

The values in Table 12 should be interpreted as follows. The incremental value of spectrum below 1 GHz to public mobile services is ascribed a value of 1.0. All other values across applications and bands are set relative to this value. We have proposed zero values in frequency ranges where the high cost of service deployment, technical barriers, or the limited bandwidth available mean the service would not be deployed in practice. Intermediate values are derived using the data reported in Annex 1. Because the data used to calibrate the relative values are at best partial and approximate we have looked for order of magnitude differences in value.

The size of useful increments of spectrum varies significantly between applications. In particular, for private mobile radio and short range devices, incremental requirements can be relatively small – say up to 10 MHz in total. For other applications, such as public mobile and satellite services, the blocks required to support provision of services by multiple operators are typically much larger – say 50 to 100 MHz and more. We have colour coded those applications that require relatively small amounts of spectrum in red in Table 12.

40 This is to say that rankings are transitive. Recall, too, that if the price paid for band A is greater than that paid for band B, then under suitable assumptions the welfare gain associated with band A can also be assumed to be greater than that for band B.

41 In these cases cost savings offered by particular bands provide an indicator of the economic value of the resource for these applications – we are not aware of measures of the economic welfare gained from improving the quality of the output produced (e.g. security).

Table 12: Index of incremental value/MHz/pop for harmonised allocations by application and frequency band

	400-600 MHz	600 MHz - 1 GHz	1-2.1 GHz	2.1-3 GHz	3-4 GHz	4-6 GHz
Cellular/BWA	0.01	1	0.5	0.1	0.01	0.001
Broadcasting (Terrestrial)	0.5	0.1	0.01	0.001	0	0
PMR/PAMR	0.1	0.1	0.01	0.01	0	0
Fixed links	0.1	0.1	0.005	0.001	0.001	0.001
PMSE[42]	0.1	0.1	0.01	0.001	0.001	0.001
Satellite (civil)	0.1	0	0.005	0.005	0.005	0.001
SRDs[43]	1	1	0.1	0.01	0.001	0.001
WTDS (WiFi)	1	1	1	1	0.1	0.1

Public mobile services for frequencies in the range 700 MHz to 1 GHz are denoted with a value of 1.0. Red colour coding indicates applications that require relatively little additional spectrum (typically less than 10MHz).

In summary, for frequencies up to 1 GHz, mobile applications and SRDs are the highest value uses, though these values apply to relatively small incremental blocks for SRDs as compared with mobile applications. Lower frequency bands are generally not of great value for fixed link and satellite services because of the limited bandwidth available, though some high value narrow bandwidth services (e.g. for telemetry control of critical applications such as fault notification for utilities) have requirements below 2 GHz.

The types of data and information sources used to develop the above table for frequency ranges up to 6 GHz are as shown in the table below.

42 Below 1 GHz, the applications are mainly wireless microphones and talkback. Above 1 GHz, wireless cameras and video links are deployed.

43 For SRDs below 1GHz, small amounts of spectrum (1-2 MHz) can be of high value.

Table 13: Information sources for the economic value of different applications

Service/application	Information available	Bands for which data is available
Terrestrial TV broadcasting	Estimates of incremental economic value (Digital Dividend (DD)) in several countries) Estimate of opportunity cost value (UK)	790-862 MHz 470-862 MHz
Public mobile services	Auction results (numerous countries) Incremental economic value for recent reallocations (DD)	800, 900, 1800, 2100, 2.3 GHz, 2.5GHz
Wireless broadband services	Auctions results (various countries and bands)	3.5 GHz, 1780MHz
Short range devices	Estimates of economic value of entire spectrum used (UK)	Many bands
WiFi	Estimates of economic value of entire spectrum used (UK)	2.4 GHz
Private mobile radio	Opportunity cost prices (UK) Auctions	VHF and UHF bands 400 MHz
T-DAB/multi-media broadcasting	Auction (UK) Economic value estimates for FM50	1.4 GHz
PMSE	Estimated economic value (Digital Dividend)	470-862 MHz
Fixed links	Auctions results (UK, Norway) Opportunity cost estimates (UK) Economic value estimates (UK)	Many bands – mainly above 6 GHz
Satellite (civil)	Opportunity cost estimates (UK) Licence fees (Europe for MSS) Economic value estimates – broadcasting (UK and Europe)	Bands at 1-2 GHz for broadcasting and MSS Bands at 3 GHz and above for fixed and broadcasting services

4.6.3 Possible approaches where there are no measures of social value

Social considerations interact with technical and economic in complicated ways. The Treaty on the Functioning of the European Union (TFEU) recognises numerous social goals that are reflected in European regulation of electronic communications, including (1) preserving the safety of property and human life, and (2) safeguarding cultural diversity and media pluralism.

The complexity of resultant trade-offs among technological, economic and social factors is visible, for example, in Article 9(3) of the Framework Directive as amended in 2009, which permits proportionate and non-discriminatory deviations from technological neutrality only where this is necessary to:

- avoid harmful interference;
- protect public health against electromagnetic fields;

- ensure technical quality of service;
- ensure maximisation of radio frequency sharing;
- safeguard efficient use of spectrum; or
- ensure the fulfilment of a general interest objective …

Article 9(4) of the Framework Directive goes on to provide examples of a number of relevant general interest objectives[44] including, but not limited to:

- safety of life;
- the promotion of social, regional or territorial cohesion;
- the avoidance of inefficient use of radio frequencies; or
- the promotion of cultural and linguistic diversity and media pluralism, for example by the provision of radio and television broadcasting services.

The efficiency analysis must appropriately take these factors into account; however, it is important to avoid a superficial analysis.

Starting with the issue of objectives other than efficiency, we observe that historically spectrum has been allocated to:

- Defence to support national security objectives;
- Aeronautical services to support safety of life objectives though over time radio navigation, location and communications have also been used to support rapidly growing levels of sector activity whilst not compromising safety;
- Maritime services to support safety of life objectives;
- Meteorology to support safety of life and defence objectives (amongst others);
- Radio astronomy to support pure research objectives; and
- PPDR to achieve certain protection of life and personal security objectives.

Are these really cases where we cannot determine the value of spectrum?

Determining the economic and social value of national defence or pure scientific research may be not appropriate because the level of activity society chooses is not governed by efficiency considerations; rather, the level of activity is determined through a political process, and the chosen level of activity is expected to be delivered cost-effectively. However, even in these, cases the production function for the final output (defence, scientific research/knowledge, safety) may allow for substitution between spectrum and other inputs (e.g. transmission equipment). Furthermore, there may be

44 The text notes that general interest objectives are "as defined by Member States in conformity with Community law".

possibilities for substitution between different frequency bands and/or communications platforms. In other words, the spectrum users may have the flexibility to:

- Use alternative frequency bands that have spare capacity;
- Use an alternative wired service – though options here will tend to be limited for defence, aeronautical/maritime and science applications;
- Use a more efficient technology that requires less spectrum;
- Substitute infrastructure for spectrum (for example, investment in shielding sites, better receivers, building more infrastructure to get greater reuse).

The value of spectrum to the user will be greater the more costly it is to make any of these changes. These costs may include one or more of:

- Additional equipment costs;
- The change in operational costs (these could be positive or negative);
- The costs of managing the change in equipment and systems which may include the costs of dual running for critical systems;
- The transaction costs associated with negotiating new harmonisation measures (if required) and negotiating other aspects of access to new bands (technical conditions, ECC measures, and so on);
- A possible loss of flexibility in accommodating new requirements.[45]

Several examples may help illustrate these points:

- In France, the Ministry of Defence gave up its use of the 2.6 GHz band in exchange for a payment of €67m which was used to pay for moving of around 700 tactical links (the RUBIS systems) to another band.[46] This implies a value of spectrum to defence of €0.353m/MHz (€67m/190MHz) or €0.005/MHz/pop.[47] (We assume there was no loss in functionality as a result of the change.)
- In the UK, radio astronomy users voluntarily gave up use of 606-614 MHz. This followed a negotiation between HM Treasury and the Department for Innovation, Universities and Skills. The latter body (which is the government department responsible for radio astronomy amongst other things) received "considerable financial benefit" as a result of releasing channel 38.[48] The increased budget will

45 Note this is what economists call the option value of spectrum. It will be included in market values of spectrum revealed through trades and auctions.
46 The process is described in ANFR annual reports. For example the 2007 report can be found at http://www.anfr.fr/fileadmin/mediatheque/documents/organisation/RA_2007VA.pdf
47 French population is 65m. http://www.rivieratimes.com/index.php/provence-cote-dazur-article/items/french-population-hits-6535-million.html
48 See para 4.25 of Section 4 of Digital Dividend Review: 550-630 and 790-862 MHz, Ofcom Consultation document, June 2008 http://stakeholders.ofcom.org.uk/binaries/consultations/clearedaward/summary/condoc.pdf

be used to fund the future projects in UK radio astronomy including UK participation in the international Square Kilometre Array. The size of the payment was not published, but it appears that UK radio astronomers have substituted use of the 606-614 MHz band for (amongst other things) access to the results of spectrum use by radio astronomy in other countries.

- VHF (118-137MHz) communications between aircraft and ground have historically used 25 kHz channels. Within Europe, the band has become congested, and one measure to address this has been the migration to narrower bandwidths for aircraft flying above 24,500ft (FL245) and later above 19,5000ft (FL195).[49] Eurocontrol estimated the potential financial costs and spectrum benefits of moving from FL245 to FL 195 for 8.33 kHz communications on a European basis.50 These data can be used to calculate the average cost of releasing additional channels for VHF communications. That 20 countries have moved to FL 195 for commercial aircraft[51] suggests that the benefits of this action exceed the costs. The average cost estimates could be said to give a lower bound on the marginal benefit from the release of additional VHF communications spectrum.[52] This value is €18m/MHz (=€24m/1.35 MHz[53]).

In summary, these examples suggest an approach to valuation that is based on the extent to which substitute bands/technologies/platforms are available that would enable more efficient use of the spectrum. At a high level, we would expect the following ordering of value:

- High value bands would be those where all of the following conditions apply:
  - The application (and the users) are mobile (not fixed)
  - Technology in use is recent
  - The band is internationally harmonised
  - A very large amount of equipment uses the band (globally)
- Low value bands would be where one or more of the following conditions apply:
  - The application is fixed and national
  - The technology is old (and there is more efficient technology available)
  - There is a small amount of equipment in use in the band

49 http://www.eurocontrol.int/articles/833-khz.
50 Eurocontrol (2006), Justification material for the draft implementing rule on air-ground voice channel spacing http://www.eurocontrol.int/ses/gallery/content/public/docs/ru/SES_IOP_VCS_JMA_v2.0.pdf.
51 This is not necessarily the case for military aircraft. See http://www.eurocontrol.int/articles/state-aircraft.
52 Aeronautical and maritime spectrum pricing, Indepen and Aegis for Ofcom, April 2007.
53 The spectrum is released in the UK, France and Italy, all of which have particularly congested airspace.

Moderate value bands sit between these two extremes. Examples of high value bands are internationally harmonised bands for aeronautical and maritime mobile applications. Low value bands could be those used for fixed links to support a defence and PPDR. Moderate value bands could include those used for radio astronomy where geographic substitutes may be possible.

The key point here is that many of the measures that could be undertaken to improve efficiency in a given band do not destroy the social value of the relevant service, and many do not impact the value of the service (except perhaps to the extent that the transition may be disruptive). The introduction of newer and more efficient technology into a band may enhance the social value of a service rather than reducing it (as was the case with the transition from analogue to digital television broadcasting). Similarly, if a service is moved to another band due to re-farming, it does not necessarily mean that the social value of the service is lost.

Thus, it is not impossible to make broad statements about the social value associated with a spectrum band or application. Nonetheless, given (1) the challenges in quantification, and especially given (2) that any positive or negative impact is heavily dependent on the specific measure proposed or selected to improve efficiency, we feel that social efficiency and effectiveness is most appropriately considered, not at the time that candidates for improved efficiency are identified, but rather at the point where measures for improvement are considered and assessed.

4.7 Economic and social value indicators of a proposed measure to address inefficiency

As noted earlier in this chapter, it is crucial to distinguish between economic measures associated with (1) the application, (2) the band, and (3) possible measures to be taken. Failure to do so would risk confusing the *problem definition* with the *proposed solution*, and thus making the analysis confused, circular and intractable.

This section deals with the economic characteristics of proposed or possible measures that could be implemented to address perceived inefficiencies.

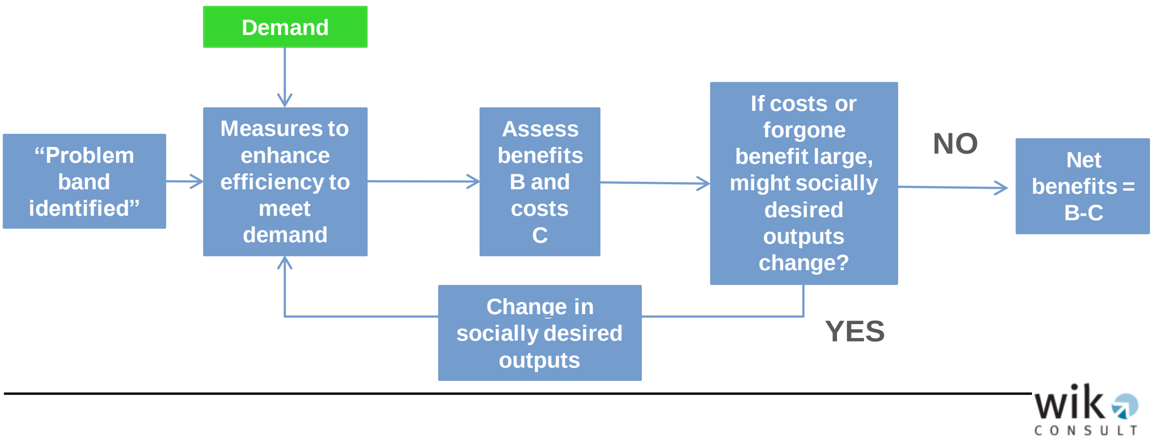
4.7.1 Identifying measures to be taken

A set of spectrum allocations and assignments is said to be economically efficient if there is no other set of allocations and assignments that produces higher net economic benefits (i.e. benefits less costs). Economic benefits and costs are measured in monetary terms where possible, although sometimes only a qualitative or ordinal indication of their scale is feasible.

This section deals with the economic and social indicators that could be used to assess proposed or possible measures that could be implemented to address perceived inefficiencies. There could be a conscious decision that no action is warranted, for example because there is no demand for the band in question; however, where there is likely to be demand for the spectrum, a variety of possible measures might be considered, and their costs and benefits would need to be assessed to determine which course of action is likely to offer the greatest net benefits to society.

Figure 3 shows the steps in the process. The benefits and costs of possible measures to enhance the efficiency of spectrum use are evaluated in quantitative and qualitative terms, including an assessment of when they might be realised (i.e. their timing). There will be some socially desired outputs defined through a political process that will be assumed to be unchangeable in the first instance (i.e. reductions in these outputs cannot be compensated for by benefits from other applications); however, in Figure 3 we show a feedback loop which might be implemented in which the nature of the socially desired outputs is reassessed if the costs of maintaining them (in terms of direct expenditures such as the costs of migration or forgone benefits from use of the spectrum by other services) were found to be very high.

Figure 3: High level process for evaluating potential policy interventions



In the remainder of this section of the report, we elaborate on the methodology to be employed and discuss the economic and social costs and benefits that might be associated with different specific interventions, and illustrate the ideas with a number of examples.

4.7.2 Features of the analysis

A set of spectrum allocations and assignments is said to be economically and socially efficient if there is no other set of allocations and assignments that produces higher net economic and social benefits (i.e. benefits less costs). Economic and social benefits and costs are measured in monetary terms where possible, although sometimes only a qualitative or ordinal indication of their scale is feasible.

The Spectrum Inventory is primarily concerned with the spectrum allocated to particular applications, the extent of actual spectrum use by those applications, and the associated usage rights. We assume that assignment issues are either left to market forces (e.g. auctions, spectrum trades or leases) or managed administratively (e.g. using on a first come first served basis); however, even with this narrowing of the task, it is not likely to be possible to determine the economically efficient allocation spectrum analytically. Such analysis would require information on the consequences of many hundreds of potential changes in allocations on future technology development, service and equipment markets, and the interference environment as these impacts affect the economic benefits and costs of using and re-farming the spectrum. This is clearly not practical.

Furthermore, any analysis must consider the particular pattern of allocations and assignments that exist today, rather than a blank sheet of paper. While in principle it may be possible to move from the current situation to the economically optimally efficient allocation and assignment, there are many practical reasons why this is not feasible. A more realistic objective is to seek progressive improvement in the economic and social benefits derived starting from the existing allocations and assignments.

In analysing possible improvements, it is important to bear in mind that the value of the application is in most cases not itself the issue. In most realistic cases, the application will continue to be supported (assuming that it continues to have value). The question is the degree to which a proposed progressive improvement *changes* the costs or benefits of the impacted applications, for better or worse.

A partial analysis that seeks to identify and rank measures that could be taken to improve the efficiency of candidate bands or applications is potentially possible. Key features of this analysis are as follows:

- It is concerned with identifying the *incremental* costs and benefits associated with a change in use of a band/bands and not the absolute value of current and prospective applications in the band. The benefits typically relate to the deployment of new of more applications, whereas the costs usually relate to transition and transaction costs caused by the change. These costs often fall on incumbent users and are situation specific;[54] however, changes in spectrum use will typically not result in the loss of a service/application but rather are more likely to cause a change in the costs of providing it or the quality of the service.

54 For example they are likely to be higher the greater the current use of the band and/or neighbouring bands and the newer the equipment that is currently using the band.

- It involves analysis of *current and future* economic and social costs and benefits and their possible timing. The costs of change may be reduced by delays in implementation, because users have more options for adjusting to the change, but delays could reduce the scale of benefits. These impacts need to be taken into account in the analysis. Benefits and costs that can be quantified are put on the same basis by applying a discount rate to benefits/costs incurred in year t where the discount factor equals $1/(1+r)^t$, where r=the social discount rate.[55]

- It should take account of the *substitutability of different bands* for delivering applications. If each band is analysed in isolation, there is a risk of over-counting the costs and the benefits.

- It requires specification of possible *changes in the definition of incumbents' usage rights* that may affect the use of the band under investigation. The change in usage rights has to be such that use of the band by other applications is not just a theoretical possibility, but there must be a high probability these applications will be deployed/taken up. The conditions for competitive equipment production for the band must exist and there must be some reasonable prospect of demand for the new application (and hence demand for the spectrum).

The economic efficiency of a particular allocation (versus some other allocation) and use of a band (versus some other band) cannot be identified in isolation from demand from other services, and the use of other bands. Assessing economic efficiency is clearly more complex than assessing technical efficiency, and much more data is required including information on technology used and the potential to use more efficient technology. The latter affects the regulatory options that can be considered and so the costs of any changes and the quantum of spectrum required to support incumbent and new uses.[56]

Analyses of economic efficiency are not usually concerned with the distribution of benefits and costs amongst differ users of the spectrum – it is assumed that mechanisms for winners to compensate losers will be implemented if this is thought to be socially or politically desirable. Similar issues arise when considering whether to aggregate the impacts of specific measures across the different EU member States. If impacts on some groups of users or Member States are considered to be more important than others in policy terms, then higher weights can be given to these groups (e.g. in some policy analysis impacts on low income households are given higher weight than others[57]) or the issue can be addressed qualitatively once the impacts have been assessed. We assume that, in the context of the Spectrum Inventory, these decisions are made through the normal political process.

55 The European Impact Assessment Guidelines recommend a discount rate of 4%. This is based on the average yield on long term debt in the EU since 1980.

56 This needs to take account of the need for guard bands and the configuration of the spectrum e.g. whether it is paired or not.

57 For example, UK guidance on the weights given to different income groups is given in HM Treasury's Green Book. http://www.hm-treasury.gov.uk/d/green_book_complete.pdf.

4.7.3 Types of benefits and costs to be assessed

The "solution" to inefficiency could include one or more of the following measures:

- Spectrum re-farming to re-allocate or reassign a band in a specific geographic area;
- Employing new technology to improve the efficiency of use of spectrum in its current application;
- Enabling increased sharing of the band in question in the relevant geography; or
- Establishing harmonization across a broader geographic area, or eliminating or reducing the constraints imposed by harmonisation that is already in place.

In the first three cases, the change would tend to be associated with making more spectrum available, either for the existing application or for a new application. The fourth measure might enhance the value of the spectrum by allowing new or different applications and technologies to be deployed in the band.

To assess the benefits and costs of any measure, the following impacts would need to be assessed relative to a base case of no change:

- Benefits from a new or more intensive use of the spectrum. To evaluate these benefits, it is necessary to evaluate the value of the additional use of spectrum either:
  - Quantitatively e.g. estimating economic and social welfare in monetary terms or in terms of number of users or volume of equipment using the spectrum; or
  - Qualitatively e.g. estimating the extent of contribution to a specific policy objective.
- Costs may be incurred if incumbent users are required to migrate to an alternative band, platform or technology, or to adapt their existing equipment in some way. Costs should be assessed on a "like for like" basis in terms of the quality of service provided by the application. These costs could include:
  - The net equipment costs of the proposed solution – this is the cost of new equipment less the depreciated value of existing equipment. If equipment is at the end of its economic lifetime, then there is no net economic cost.
  - Any net on-going operating costs.
  - The costs of disruption in service delivery associated with making a change.

- Costs may be incurred by users in neighbouring bands if there is an increased risk of interference to their transmitters or receivers in those bands. These costs may be manifested as either degradation in service or as the cost of filters, shielding or other actions that could mitigate the interference.
- Transaction costs may be associated with the process of negotiating and making the changes. These costs tend to be relatively minor, and include the salary costs and other expenses incurred by regulators, spectrum users and other parties associated with making regulatory changes.

Some of the data captured by the inventory that is used to assess technical efficiency could be used for quantifying these costs, such as data on:

- The volume of equipment in use;
- The technology used, or
- The numbers of end users.

Also, the information reported earlier in this section on the relative economic value of spectrum in different applications/bands may be useful in understanding the potential scale of any benefits. In addition, bespoke studies may be required to examine in detail the costs and benefits of options for enhancing the efficiency of use of a particular band.

In the following sub-sections, we have provided real world examples of changes in policy aimed at enhancing the economic and social efficiency of spectrum use.

4.7.3.1 Reallocation of spectrum and technological enhancement: the Digital Dividend

An example where estimates of consumer and producer surplus were used to assess the economic efficiency of changing allocations (and assignments) at a European level is the policy decision concerning the future harmonised use of the “Digital Dividend” arising from digital TV switchover. Indeed, the digital dividend serves both as an example of technological enhancement, and of spectrum reallocation.

The migration from analogue to digital TV transmission represents perhaps the most significant example of technological enhancement in the last 5 to 10 years. The benefits of this migration have included:

- Better quality TV services – higher resolution pictures including the possibility of HD as well as SD digital images;
- More services within a given 8 MHz TV channel; and
- Spectrum release for more TV and/or other services.

On the other hand the costs of migration have included:

- The costs of a new digital TV transmission infrastructure
- Consumer costs associated with buying new receivers – set top boxes and integrated TV sets – and in some cases new rooftop aerials
- The operating costs of dual operation of analogue and digital TV infrastructure (in most but not all countries)
- The costs of public education and publicity about the switchover
- The costs of negotiating a new TV transmission plan for Europe

The European Commission commissioned a study that examined the economic benefits from reallocating 790-862 MHz on a harmonised basis from television to mobile use, assuming that digital switchover would happen in any event. The study quantified:

- The incremental economic benefits from using the spectrum for mobile broadband.
- The minimum of the incremental benefits foregone from using the spectrum for digital TV, and the costs of creating further DTT multiplex capacity in the spectrum below 790 MHz (e.g. by adopting more efficient compression and transmission standards).

An alternative approach using market prices could have been used. For example, for the US, Bazelon (2009)[58] estimates:[59]

- the value of spectrum for mobile broadband from auction data for other frequency bands, and subtracts from this
- the costs of clearing the TV band and maintaining a comparable TV service to users using other platforms.

This shows a significant net benefit. Bazelon obtains similar results when calculating consumer and producer surplus for the different regulatory options.

This example shows that the information required to assess economic efficiency is not readily available, although the use of market information can reduce the information burden. It also shows that some costs can easily be missed – for example, neither of the studies referred to above counted the costs associated with interference from LTE services into TV receivers.

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58 "The need for additional spectrum for wireless broadband: The economic benefits and costs of reallocations, C Bazelon, The Brattle Group, 2009.

59 He also consider cases where the service is not maintained to consumers and there is a loss of financial value for broadcasters which is estimated and shown to be much less than the value of the spectrum to the mobile operators. The proposed FCC incentive auctions for the 600 MHz band would have the effect of making this cross payments and it is possible some of the receipts could also be used to repack the frequencies and provide a lifeline TV service to consumers.

4.7.3.2 Enabling increased sharing – white space at UHF

Ofcom has assessed the benefits and costs of providing access to white space in the UHF TV band using geolocation databases.[60] It estimated the economic and social benefits from a range of applications that may be enabled (e.g. household and business WLANs, municipal WiFi, and machine-to-machine communications) as being in the range of £200-320m.

The costs are those associated with developing the necessary regulations, establishing and operating the geolocation database(s), and any increased risk of interference. Ofcom considered the latter to be minor, and did not assess the other costs.

4.7.3.3 Changing harmonisation measures

The EC recently commissioned analysis of the costs and benefits of liberalising the use of the 2 GHz band to allow WAPECS services in the band.[61] The benefits calculated were those to consumers and operators associated with the deployment of LTE rather than UMTS technology in the paired frequencies (less the costs of this deployment) and the benefits of a variety of possible applications (downlink only, machine-to-machine communications, and PPDR communications) in the currently unused TDD blocks (1900-1920/2010-2025 MHz). Depending on the demand and deployment scenario, the net benefits were up to around €1 billion.

60 See Ofcom's impact assessment ofr White space access to the UHF frequency band using geolocation databases. http://stakeholders.ofcom.org.uk/binaries/consultations/geolocation/summary/geolocation.pdf.

61 The 2GHz band comprises 1900-1920 MHz and 2010-2025 MHzconfigured for TDD use and 1920-1980MHz/2110-2170MHz configured for FDD use. See http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/studies/2ghz/support2ghz_ia_final_report.pdf.

5 Benchmarking

The purpose of this section is to report on spectrum inventory activities undertaken by various regulators and/or governments. This includes activities aimed at understanding the status of current spectrum use, identifying future spectrum requirements, and changing the permitted use of bands so as to accommodate future demand. We have not attempted to provide a comprehensive review of such activities, but rather have focussed on a small number of countries in each ITU region that have published relevant information. The countries reviewed are as follows:

- ITU Region 1: Denmark, France, Ireland, Netherlands, Sweden and the UK
- ITU Region 2: the US
- ITU Region 3: Australia and Japan

The information presented here is based on desk research of published materials and the interviews with stakeholders that were undertaken as part of the data collection activity in this study. More detailed information is given in Annex 2.

5.1 Nature of the spectrum review activities

In tables below we indicate the nature of spectrum review activities in the benchmark countries. Table 14 indicates whether a spectrum inventory is being or has been undertaken and, if so, the frequency and scope of the activity. In most but not all countries, some form of inventory has been undertaken. About half of the countries that have conducted a spectrum inventory have done so on a one-off basis, while others have a rolling programme that updates usage information either annually or on a three year cycle.

Table 14: Nature and scope of spectrum inventories

Country	Inventory?	Frequency and scope?
Australia	Yes	Updated each year in the five year spectrum outlook
Japan	Yes	Each year a third of the frequencies is assessed: bands below 770MHz; 770MHz-3.4 GHz; above 3.4 GHz
US	Yes	One-off. Main focus is on bands used by federal agencies in frequency range 225-4400MHz
Europe:		
Denmark	No	Not applicable
France	Yes	Annual. Bands are divided into three groups: under 223MHz, 223MHz-5GHz and above 5GHz.
Ireland	No	Not applicable
Netherlands	Yes	Annual for non-government use and three yearly for government use
Sweden	Yes	One off snapshot of the position today and in 2020
UK	Yes	One-off. Government and non-government use addressed by separate processes

The inventory work is aimed at identifying bands that could be repurposed so as to accommodate increasing demand. Because of the rapid changes in spectrum demand from a variety of applications, together with the long lead times on repurposing spectrum and achieving necessary international harmonisation and standardisation work, spectrum managers in many countries have undertaken spectrum demand assessments over a 5-10 year period. The results of these analyses in the benchmark countries are shown in the third column of Table 15. In most cases, the requirement is for additional spectrum for mobile broadband services, and there is ongoing work to identify bands that might be made available.

Table 15: Demand analysis and/or targets

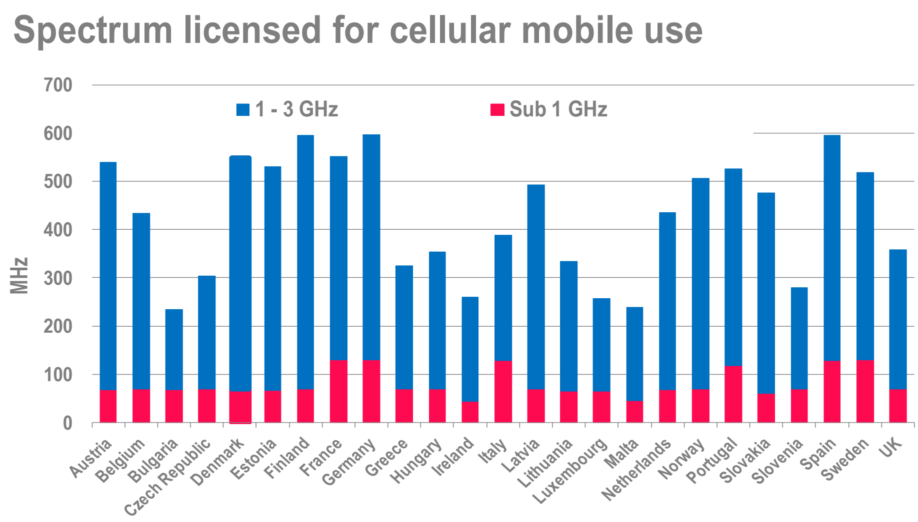
	Demand analysis	Spectrum required to meet demand for mobile broadband	Plans for candidate bands
Australia	Yes to 2016 and 2020	300 MHz by 2020, with50% of this by 2015	Candidate bands published
Japan	Yes for 2015 and 2020	3000 MHz by 2015; up to a further 1.2 GHz by 2020	Action plan published identifying a number of bands to be considered
US	Yes to 2020	300 MHz by 2015; a further 500MHz released by 2020	Some immediate releases identified and 11 priority bands are under investigation
Europe:			
Denmark	Yes to 2020	300 MHz by 2020; a further 300 MHz by 2025	Yes – priority bands for investigation identified
France	Yes to 2020	500-700 MHz by 2020	Work undertaken but not published
Ireland	No formal assessment but views derived from stakeholder consultation	No	Yes
Netherlands	Yes trend analysis – 2012 to 2016	No	No, main focus is on policy response
Sweden	Yes to 2020	Under study together with demand from other applications	Yes, will be an output of the process
UK	Yes for commercial applications.	500 MHz of public sector spectrum by 2020	Candidate bands published

Table 16 shows the amounts of spectrum currently allocated to cellular mobile services in Europe, the US, Australia and Japan in bands below 3 GHz. In most cases, the spectrum has all been assigned (or will be assigned in the next year); however, in Japan there is a significant difference between the amounts allocated and assigned, so we have indicated the amounts assigned in brackets. Also the situation in respect of assignments differs across the EU as shown in Figure 4. As can be seen from Table 16, Japan and Australia have significantly more spectrum allocated for mobile services than the EU or the US.

Table 16. Spectrum allocated to cellular mobile services for selected countries.

	EU	US[62]	Japan[63]	Australia[64]
700/800 MHz	60	70	72 (60)	90
800/900 MHz	70	72	115 (90)	95
1500 MHz	-	-	97 (77)	-
1800/1900 MHz	150	120	210 (115)	150
2Ghz	155	90	135 (120)	140
2.3 GHz	-	25	-	98
2.6 GHz	190	194	120 (60)	140
Others	-	23	-	-
Total	**625**	**594**	**749 (522)**	**713**

Figure 4: Spectrum assignments for mobile in EU countries



Source: ECO, April 2012

62 Source: FCC - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-11-103A1.pdf
63 Amount allocated shown and amount assigned in brackets. MIC http://www.tele.soumu.go.jp/e/adm/freq/search/actionplan/index.htm; Asia Pacific Telecommunity http://www.apt.int/sites/default/files/APT-AWF-REP-15_APT_Report_on_Mobile_Band_Usage.doc
64 Towards 2020 – future spectrum requirements for mobile broadband, ACMA 2011 http://www.acma.gov.au/webwr/_assets/main/lib312084/ifc13_2011_toward_2020-future_spectrum_requirements.pdf

5.2 Candidate bands

The process used by regulators for the choice of candidate bands to meet future demand is not always published; however, in the US, the criteria used for the identification, prioritisation and evaluation of bands have been published and relate either to the benefits or the costs of the change as follows:

Benefits

- the amount of useable bandwidth to support wireless broadband and the degree to which that spectrum is contiguous;
- industry interest in the band and the expected auction revenue, if applicable, that the band will yield;
- indirect benefits to the economy of making the band available for wireless broadband; and
- the likelihood that the band can be repurposed within ten years.

Costs

- the availability of comparable spectrum (or other alternative arrangements) if relocation of incumbent users is necessary. There is to be no loss of existing or planned government capabilities in connection with a reallocation;
- the estimated costs of relocating Federal incumbents to another band; and
- the impact to services using global allocations that would require international negotiations to bring about reallocation.

In a similar vein, when deciding which bands to release, the UK government is looking at bands that would meet expected demand, provide value (i.e. net benefits), and are feasible to be released.

Table 17 lists the most commonly identified candidate frequency ranges for meeting future spectrum demand together with the countries where the band is being considered, the amount of spectrum that is being targeted and whether the future use will be on a shared or an exclusive basis. The bands inevitably differ by ITU region. However, there is some commonality in the frequency ranges being considered, in particular:

- the 1.4/1.5 GHz range which is already harmonised for use by mobile broadband services in Japan but not elsewhere, though CEPT FM50 is examining this issue in part of the band

- the 2.3 GHz band which is harmonised for mobile broadband services and is assigned in a number of countries including many in the Asia Pacific region (e.g. China, Hong Kong, India and Malaysia, Singapore, Australia), North America and Norway.
- the 3.4 - 4.2 GHz range, part of which is harmonised for IMT services in Europe.

The other development that is evident from the table is that in many cases it is expected that spectrum released for new applications will need to be shared with incumbent services.

Table 17: Main candidate bands for meeting future spectrum demand

Frequency range	Country and specific frequency range	Maximum bandwidth that might be released
450-470 MHz	Sweden	20 MHz
470-790MHz	Denmark	320 MHz
	US (VHF and UHF TV bands)	120 MHz
800-960 MHz	Australia (803-960 MHz)	30 MHz
	Sweden (871-876/916-921MHz)	10 MHz
	UK (870-872/915-917 MHz)	4 MHz
1300-1390 MHz	US	90 MHz on a shared basis
1.4/1.5 GHz	Australia (1427-1511 MHz)	83 MHz
	Denmark (1427-1518 MHz)	101 MHz
	France (1375-1400/1427-1452 MHz)	50 MHz
	Ireland (1452-1492 MHz)	40 MHz
	Sweden (1452-1492 MHz)	40 MHz
	Japan (1427-1525 MHz)	20MHz
	UK (1427-1452 MHz)	25 MHz on a shared basis[65]
1695-1710MHz	US	15 MHz
1755-1850MHz	US	95 MHz
1785-1805 MHz	Denmark	
2000-2020/2180-2200Mhz	US	40 MHz
2010-2025 MHz	Ireland, Sweden	
2025-2070 MHz	UK	45 MHz on a shared basis

65 The 1452-1492 MHz band has already been assigned.

Frequency range	Country and specific frequency range	Maximum bandwidth that might be released
2.3 GHz	Denmark, Ireland, Sweden	100 MHz
	UK	40 MHz
	US	25 MHz on a shared basis
2.7-2.9 GHz	Sweden	200 MHz
	US	Sharing potential to be examined
2.9-3.4 GHz	US	Sharing potential to be examined
3.4-3.6GHz	Australia	200 MHz
	Japan	200 MHz
	UK	160 MHz
	US	100 MHz on a shared basis
3.6-4.2GHz	Denmark (3.8-4.2 GHz)	400 MHz
	Japan (3.6-4.2 GHz)	600 MHz on a shared basis
	Sweden (3.8-4.2 GHz)	400 MHz
	US	200 MHz
4.4-5GHz	Japan	500 MHz
	UK	50 MHz
5 GHz	US	120 MHz shared for WiFi

6 Assessment of technical efficiency of bands today

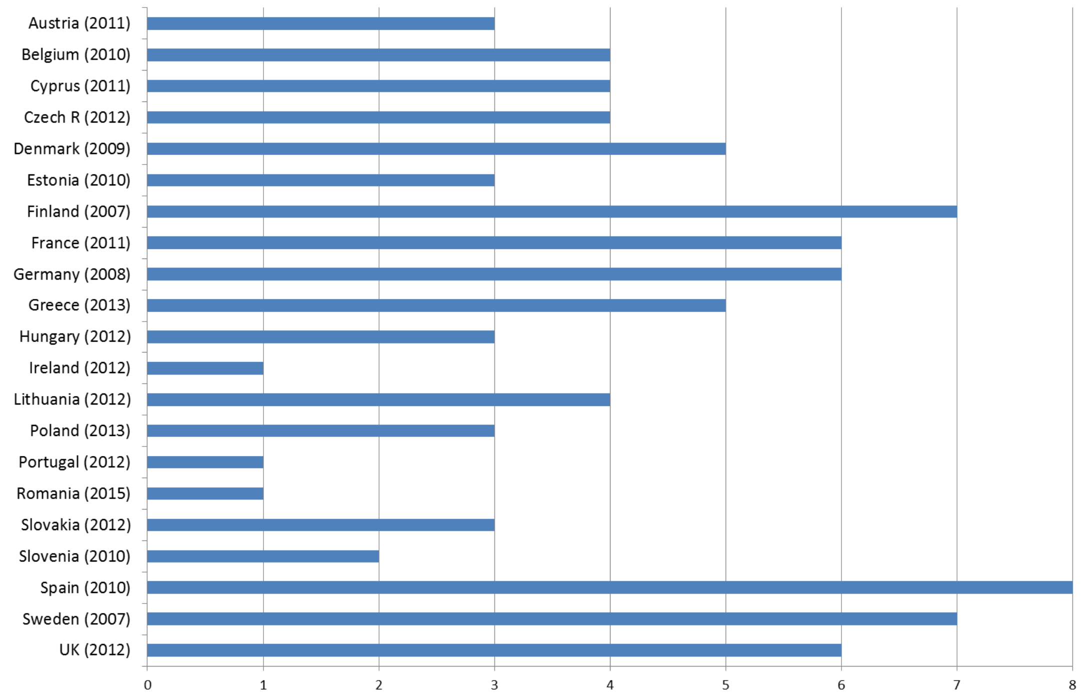
Based on the information that we have gathered and collated from SMAs and other stakeholders, it is clear that some bands, such as the core 2G and 3G cellular bands, the 2.4 GHz ISM band and the main UHF aeronautical band (960-1164 MHz) are heavily used across all Member States. Other bands have been identified as substantially unused across Europe, for example the former L-band DAB allocation (1452-1492 MHz) and the 2 GHz mobile satellite bands. Between these two extremes, many bands vary widely in the extent to which they are currently utilised in different territories.

Some examples are highlighted in this chapter of the report.

6.1 Terrestrial Broadcasting

There is considerable variation in the progress that has been made by Member States as regards both the switching off of the analogue TV service, and the rolling out of the full suite of digital multiplexes provided for in the Geneva 06 agreement (GE-06). In general, the GE-06 plan provided each country with sufficient frequencies to accommodate up to 8 national DTT multiplexes. The subsequent decision to allocate the upper 72 MHz of the UHF TV band to mobile use leaves sufficient spectrum for at least 6 national multiplexes per MS, but as the following chart illustrates, the number of operational multiplexes in many cases is somewhat lower.

Figure 5: Completion date for analogue switchover and current operational status of DTT by Member State



There are also significant variations in the technologies deployed. Most deployments currently use the original DVB-T standard with MPEG4 compression, but some earlier deployments use the less efficient MPEG2 standard, whilst some of the more recent deployments are based on DVBT-2, which represents the current state of the art in terms of spectrum efficiency.

Another factor which may influence the spectrum efficiency of digital broadcast networks is whether a single frequency network (SFN) or multi-frequency network (MFN) is deployed. This was raised, for example, in a recent Radio Spectrum Policy Group paper on the future of the 700 MHz band.[66] Unlike most legacy radio technologies, the OFDM technology used in the DVB-T standard enables the same frequency to be re-used by multiple transmitters within a given geographic area, so long as there is sufficient synchronisation between the transmitters making up the network. The DVB-T standard specifies a range of “guard intervals” between transmitted symbols to allow for the time delay between transmissions received from different sites or for multipath reception from the same site. The guard interval is specified as a fraction of the symbol length and can be set to a value between 1/4 and 1/32, depending on the network configuration and the required signal resilience.

In general, SFN transmissions require a longer guard interval than MFN transmissions. The size of the guard interval also sets a limit on the geographic size of an SFN, since more distant transmitters incur longer delay at the receiver, which is more likely to exceed the length of the guard interval. Hence, larger SFNs (such as might be required to cover an entire country) will require a larger guard interval, reducing the capacity of the network. Furthermore, as large SFNs are prone to self-interference between more distant transmitters during periods of enhanced propagation, lower level modulation schemes must be used to improve signal resilience, further reducing capacity. For example, according to the EBU, a large national SFN is realisable only by deploying the most rugged variant of the DVB-T standard, which reduces multiplex capacity to typically 5-6 Mbps, whereas smaller SFNs covering a diameter of up to 150 km can support capacities of up to 24 Mbps, which approaches the capacity of an MFN configuration.[67]

The emerging DVB-T2 standard provides significant improvements in SFN performance, as Illustrated by the recent deployment in Finland of a national SFN in the VHF band using an existing network of cellular sites to relay the signals, rather than conventional high power broadcast transmitters.[68] This high density network configuration reduces the likelihood of self-interference and allows the full capacity potential of DVBT-2 to be realised nationally on a single frequency; however, widespread deployment of such networks in the UHF band would require substantial revision to the existing Geneva 2006 (GE-06) frequency plan and would be incompatible with many existing DVB-T receivers.

66 RSPG 12-425, Commission services' discussion paper on the future use of the 700 MHz band in the European Union, June 2012.

67 EBU technical white paper, “General issues to be considered when planning SFNs”, March 2009.

68 “World’s first DVB-T2 network in SFN mode”, TVB Europe, 11 September 2011, www.tvbeurope.com/main-content/full/world-s-first-dvb-t2-network-in-sfn-mode.

It should also be noted that whilst SFNs provide an obvious saving on spectrum within the immediate coverage area, different frequencies will still need to be deployed in neighbouring regions or countries, and within countries where there is a requirement for regional content or to cater for different languages. Hence, on a European basis, the total number of frequencies required is unlikely to differ significantly whether MFNs or SFNs are deployed. Whilst SFN deployment at a national level should result in wider geographic availability of individual “white space” frequencies that could be used by low power cognitive technology (which in some cases could extend over entire countries), it would be unlikely to lead to any reduction in the overall European requirement for digital TV spectrum.

Taking account of the above, we have concluded that, whilst SFNs based on the DVB-T2 standard have the potential to provide significant benefits in the longer term, particularly if deployed over high density transmission networks, these benefits are far less clear for conventional DVB-T networks and in any case would be dependent on substantive revision of the existing ITU frequency plan. We have therefore not included the network configuration in our assessment of efficiency at this stage, although we did ask NRAs to indicate whether SFN or MFN configurations are deployed. The current situation where data is available is summarised below – note that in most cases SFNs are deployed on a regional rather than national basis.

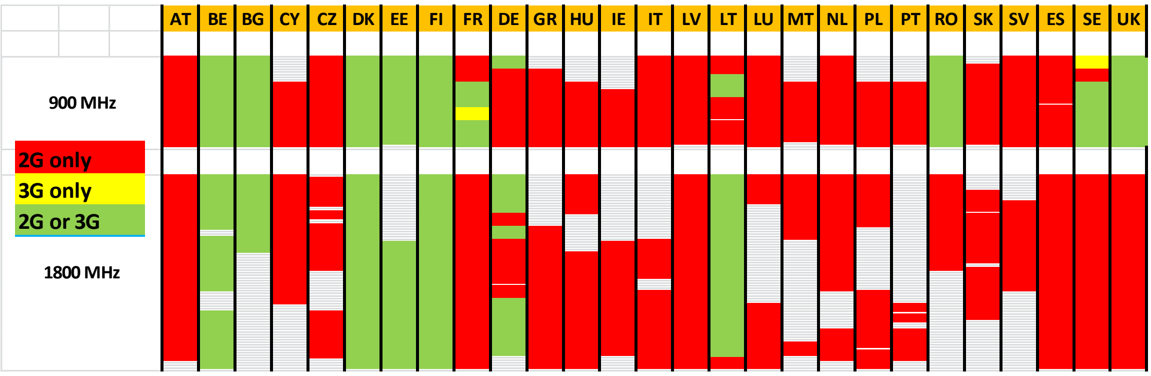
- MFN deployment: CY, CZ, FI, FR, DE, IE, IT, LT, SE, UK
- SFN deployment: DK,GR, HU, LU, NL, PL

6.2 Cellular Mobile

As noted above, the established paired cellular bands at 900 MHz, 1800 MHz and 2 GHz are in general heavily used throughout the EU, although in some countries parts of these bands still have not yet been licensed. 3G TDD spectrum around 2 GHz remains unused virtually throughout the EU, despite much of this spectrum having been licensed a decade or more ago alongside the 3G FDD spectrum. One of the few places where a TDD network was launched was the Czech Republic, where T-Mobile used the technology as an alternative to ADSL for fixed broadband connectivity; however in March 2012, T-Mobile announced the closure of this network and will be migrating users to the operator’s FDD network which deploys much faster HSPA technology.

There are wide variations in the extent to which existing 2G bands have been re-farmed to 3G technology, and in the licensing and deployment of services in newer bands around 800 MHz and 2.6 GHz.

Figure 6: Currently licensed spectrum and technologies deployed in the 900 MHz and 1800 MHz cellular bands (based on ECO Report 3)

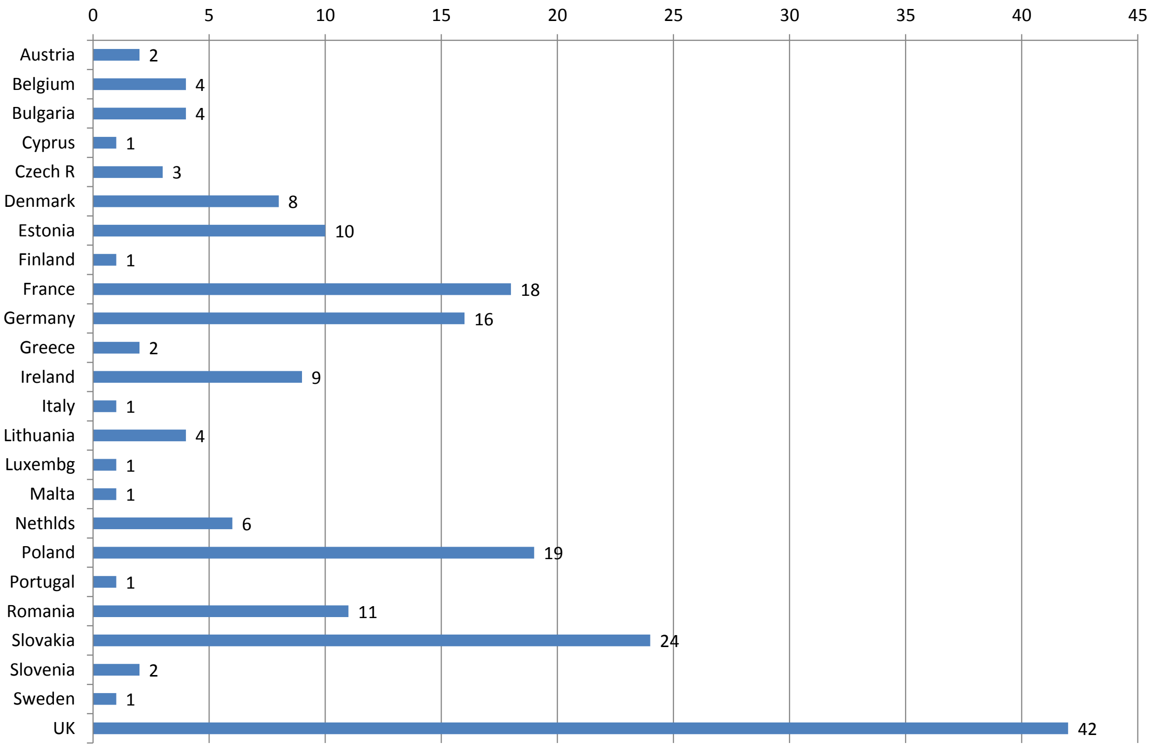


6.3 Aeronautical, Maritime and Civil Radiolocation and Radionavigation

Radars and associated systems account for a significant portion of allocated spectrum in the 400 MHz to 6 GHz range, but there are wide variations in the extent to which these allocations are used in practice. There are two principal aeronautical bands in the range, namely L-band (960 – 1215 MHz) and S-band (2700 – 2900 MHz). Both are used to a varying degree by high power, long range primary surveillance radars but L-band also accommodates a range of other aeronautical applications serving both civil and military requirements. The upper part of the band (above 1164MHz) is also used by the GPS and Galileo radionavigation satellites.

The use of S-band by civil aeronautical surveillance and weather radars varies widely, as illustrated in the chart below (note the band is also used by military radars in some countries – these are not included in the totals). In Sweden, where there is currently only a single S-band radar, the band is already under consideration for possible future refarming, whereas in the UK radar deployments are already the highest in Europe and are continuing to grow.

Figure 7: Number of operational civil S-band radars in the 2700 – 2900 MHz band



Note – data on aeronautical radars has been sourced from responses to a 2010 questionnaire circulated by the Radio Spectrum Committee and data on weather radars has been sourced from EuMetNet.

6.4 Fixed Services (point-to-point or point-to-multipoint fixed links)

Fixed links are deployed in a number of bands below 6 GHz and in most cases are used to provide connectivity between two or more points where a line-of-sight connecting path exists. In principle, such links should be capable of operation in higher frequency bands that are unsuitable for non-line-of-sight transmission, enabling the existing frequency bands to be repurposed for some other non-line-of-sight application such as mobile broadband. There are good precedents for this in that most of the existing cellular bands were in the past allocated to fixed service use.

One exception to this is the deployment of links by utility companies (gas, water and electricity) which may be used for safety critical telemetry applications at remote locations (e.g. reservoirs or electricity substations) where line-of-sight paths are not available, and hence lower frequencies are required. Such requirements may grow in the future, as smart grid networks are rolled out to improve energy efficiency and resilience. These links typically require much narrower bandwidths than other types of fixed link, however, and are unlikely to have a significant impact on overall spectrum demand.

There are three main bands below 6 GHz that are currently used by point-to-point links, namely:

- 1350-1375 MHz paired with 1492-1517 MHz
- 1375-1400 MHz paired with 1427-1452 MHz
- 3800-4200 MHz

The historic attraction of sub-3 GHz spectrum for line-of-sight fixed links has typically been the ability to deploy compact Yagi type antennas that are much smaller and lighter than the dish antennas that are deployed in higher bands. As bandwidth is limited in these lower frequency bands, applications have usually focused on narrow band requirements such as voice telephony or sound broadcast distribution. More recently, these bands have been used to support backhaul within TETRA and other narrow band digital networks. The higher bandwidths and smaller cell sizes in commercial cellular networks have favoured the use of much higher frequency bands where bandwidth is much more abundant. The 4 GHz band has historically been used for high capacity trunk links, but demand for these has fallen as most backhaul traffic has migrated to fibre or to higher frequency band, where antennas are smaller and installation costs lower.

A recent survey undertaken by CEPT requested information from SMAs on the numbers of fixed links in each frequency band. We have analysed this data and normalised by population to compare the relative level of use in each country. The results are as follows (a blank entry indicates either no deployments or no data available). Note that in some cases, one or more of the bands are used by the military and quantitative link data is not available.

Table 18: Comparative level of fixed link deployment in the 1.5 GHz and 4 GHz bands (links per million population)

	AT	CY	FI	FR	DE	HU	IE	LT	LU	PL	RO	SV	ES	SE	UK
1350-1400 MHz	1.24	44	0	0			32.1	0.31	2.27	1.63	0.28	36.2			13.9
1375-1400 MHz	0.99	4	0.77	21.2							0	6.53		28.3	
3800-4200 MHz			108		4.07	1.81		9.69			11.6	18.1			0.67

6.5 Satellite services

There are a number of bands allocated to fixed and mobile satellite services in the frequency range under consideration. Judging the technical efficiency of civil satellite services particularly in relation to individual Member States is difficult because of the international dimension generally associated with such services. The spectrum resource is inextricably linked to the orbit being used hence the term “orbit-spectrum resource”. This is particularly the case for mobile satellite services, where the location of transmitting and receiving stations is generally not known.

While it is acknowledged that there are some systems based on Low / Medium Earth Orbits (LEO / MEO), the majority of systems make use of the Geostationary Satellite Orbit (GSO). Antenna discrimination at the GSO satellite allows spectrum to be reused by the same satellite or adjacent satellites over different parts of the Earth's surface. Likewise, antenna discrimination by a user terminal on the ground allows adjacent satellites to use the same frequencies and not interfere with one another. Hence, for fixed and broadcast satellite systems, the directionality of the ground terminals allows the spectrum to be reused every 2 to 3 degrees across the orbit. For mobile systems that often support user terminals with little or no directionality, the opportunity for spectrum reuse is limited, particularly for systems having global coverage. Similarly to the equivalent terrestrial service situation, it is not sensible to compare the technical efficiency of these systems using the same metrics.

At an international level, many satellite systems (whether fixed, broadcast or mobile) appear to be using relatively efficient technology. For example, the DVB S2 standard employed for TV broadcasting and data transmission purposes is adaptive and operates very close to the Shannon limit for all propagation conditions.

At face value, therefore, the initial judgment to be made is whether a satellite system is operating a viable service (i.e. is the spectrum is actually being used). One difficulty here relates to the planning of satellite systems and the associated international coordination process. Even if a satellite is not actually operating, it may well be about to be launched. This then raises the issue of whether a satellite will in fact be launched, and the whole area of paper satellites and due diligence processes.

Once it has been established that the spectrum is being used (or about to be used), this does not necessarily mean that the system will be used to the same extent in every country. Even though at an aggregated system level it can reasonably be claimed that a satellite system is technically efficient, it does not necessarily follow that the spectrum is being used efficiently within a country or region. This will be of interest if spectrum reallocation is being considered. A case in point is the 3.6 GHz band. This is otherwise known as the satellite C-band downlink and attains more or less importance depending on the propagation conditions (i.e. rain) associated with the area in which it is being used. If utilisation in individual countries is of importance, this case also demonstrates another difficulty concerning satellite systems and that is receive-only terminals. This is a downlink and receive-only terminals are generally licence-exempt meaning that NRAs do not have a record of usage. It can be noted that the UK has introduced Recognised Spectrum Access (RSA) for this band, which does provide a mechanism for recording usage that is to be protected.

In general, we have based our assessment of satellite band utilisation on the number of transmitting or receiving terminals operating in each band. Note, however that this approach is only applicable to fixed satellite bands, and even in these bands there may not always be reliable information on the number of receive-only stations (as these are not individually licensed).

7 Findings and Conclusions

In this chapter, we present our findings and conclusions. Some of these relate to the process of producing a Spectrum Inventory, while others are observations regarding spectrum efficiency (Section 7.5) based on the data that we have collected.

The methodological findings concern the taxonomy and structure of the spectrum inventory task (Section 7.1), the potential metrics of spectrum efficiency that we have identified (Section 7.2), and the degree to which consistent data is available from national SMAs and other sources (Section 7.3).

7.1 The Spectrum Inventory as an ongoing optimisation process at European level

- It is useful to think of the spectrum inventory as a *Decision Support System (DSS)* – a set of tools to help a human analyst or decision maker to (1) identify bands and applications, and (2) to evaluate costs and benefits of alternative measures that might be used to improve efficiency. (Section 2.1)
- Data management would be a key component of such a DSS, but it should also be assumed that graphic and analytical tools will be needed. (Section 2.4)
- The EFIS database is a useful tool, but not all data required for the spectrum inventory is in EFIS, and not all relevant data belongs in EFIS. It is entirely possible to implement a system design that draws on EFIS, and avoids duplicate effort for the Member State SMAs, without inappropriately constraining the spectrum inventory. (Section 2.6)

7.2 Metrics of spectrum efficiency

- Metrics of spectrum efficiency need to also distinguish between *identification* of possibly inefficient use, and *addressing* inefficiencies. The former relates to the *problem*, the latter to the possible *solution*. Metrics to identify the problem should as much as possible be independent of possible solutions. (Section 4)
- Metrics relevant to inefficiency could relate to (1) the application, which might span multiple bands; (2) the band, which might span multiple applications; or (3) the effects of having a particular application in a particular band. (Section 4)
- Quantitative metrics have their uses where suitable data is available, but in many cases it will be necessary to use qualitative metrics.
- Whether metrics are quantitative or qualitative, it is possible to provide an approximate ranking. In this report, we have provided an initial, preliminary view of the relative economic value of applications across a range of bands.

- In many cases, a measure to improve the efficiency of a band or application does not cause the application to cease operation; more often, there are transitional and long term costs and benefits, but the application need continues to be met. For this reason, the social value of an application (and often the economic value as well) is best considered together with the costs and benefits of measures to address inefficiency, rather than as being itself an index of efficiency or inefficiency. (Section 4)

7.3 Availability and consistency of data

- In most cases, stakeholders have generally been forthcoming as regards providing data.
- For some applications, SMAs have data that is useful for estimating usage in a band; for many other applications, SMAs have little data on usage.
- There is considerable variation in the scope and level of detail of information on spectrum usage held by SMAs.
- Sector stakeholders have data on usage for some sectors, but not for all.
- The EFIS database appears to have high consistency with Member State data; however, the Member States do not all record information at the same level of detail, and they do not always record it in the same way.
- The EFIS categorisation of applications is of limited utility for this study. For our purposes, we have created a more compact and consistent classification scheme. We have reviewed our approach with the ECO, and have generally aligned it with current or potential future EFIS definitions.
- Table 19 indicates the level of information that we have been able to obtain for various services from each EU country.

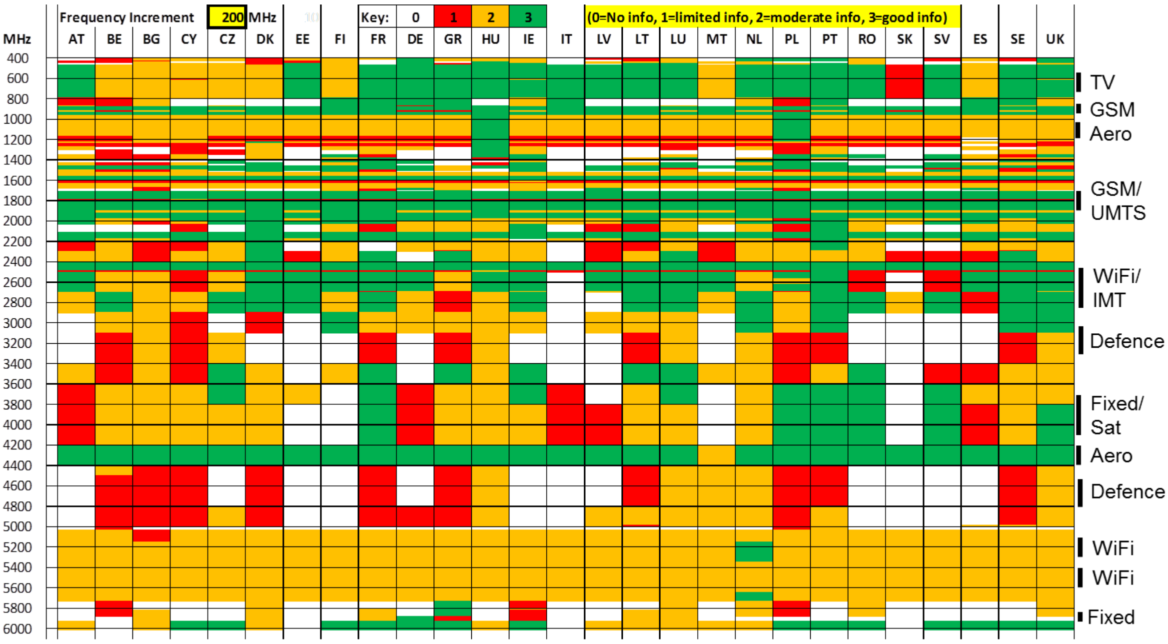
Table 19: The quality of information available from SMAs, by application and Member State

	AT	BE	BG	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SV	ES	SE	UK
General	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	!
Monitoring	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	!	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	!
Broadcast	✓	!	✓	✓	✓	✓	✓	✓	✓	!	✓	✓	✓	!	✓	✓	✓	✓	✓	✓	✓	✓	✗	!	!	✓	!
Cellular	✓	!	✓	✓	!	✓	✓	✓	✓	✓	✓	✓	!	!	!	!	!	✓	!	✓	✓	✓	!	!	!	✓	✓
Defence	!	✓	!	!	!	!	!	!	✓	!	!	✓	!	✗	!	!	!	✗	✓	!	!	!	✗	!	!	✓	✓
Fixed	✓	✗	!	✓	✓	✓	✓	✓	✓	✓	✓	✓	!	✗	!	✓	✓	✓	!	✓	✓	✓	!	✓	✓	✓	✓
FWA	!	!	!	✓	!	✓	✓	!	✓	!	✓	!	✓	✗	!	✓	✓	✓	!	!	!	!	!	✓	!	✓	!
PMR	!	!	!	✓	✓	!	✓	✓	✓	✓	✓	✓	!	✗	!	✓	✓	✓	✓	✓	✓	✓	✗	!	!	!	✓
PMSE	!	✗	!	✓	!	✓	!	✓	!	✓	✓	!	!	✗	!	!	✓	✓	!	!	✓	!	✗	!	!	✗	!
PPDR	✓	!	!	!	!	✓	✓	!	!	✓	✓	✓	!	✗	!	!	!	!	✓	✓	✓	✓	✗	!	!	!	✓
AMRCS	✓	✗	✓	✓	✓	✓	✓	!	✓	!	!	✓	!	✗	✓	✗	✓	!	!	!	!	✓	✗	!	✗	✓	✓
Scienctific services	!	✗	!	✓	!	!	!	✓	✓	✓	!	!	!	✗	!	!	✗	!	!	!	!	!	✗	!	✗	✗	!
SRDs	!	!	✗	✗	✗	!	✗	✓	✓	✗	✗	!	!	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	!	✗	✗	✗
Satellite	!	!	!	✓	!	!	!	!	✓	!	!	!	!	✗	!	!	!	!	!	✓	!	!	✗	!	✗	✗	✓

✓ Good information available ! Moderate information available ✗ Limited or no information available

The implications of this information variability for our efficiency assessment are significant, since for many frequency bands there is insufficient information to make an informed judgement about the current usage efficiency. This is illustrated in Figure 8, which shows the relative quality of information by frequency band and Member State across the EU.

Figure 8: The quality of information available from SMAs, by frequency band and Member State



In Figure 8, we have specified the quality of information in terms of three categories, namely:

- 0: No usage information available other than the allocation(s) or application(s) associated with the band.
- 1: Limited information available about usage, e.g. an application is known to be actively deployed in the band but further details such as the number of stations or demand trend are not available.
- 2. Moderate information about usage, typically sufficient to form a judgement on at least three of the four efficiency criteria, but some key information (e.g. licensing data or technology) is missing
- 3: Good information about usage, i.e. sufficient to form a judgement on all four efficiency criteria

The main source of information has been individual NRAs, supplemented by data gathered from relevant application-specific reports produced by CEPT, the EC Radio Spectrum Committee and various sector representatives.

It can be seen that there are significant gaps in information relating to bands around 1.5 GHz, 2.3 GHz, 3.3 GHz and 4.5 GHz, amounting to a significant proportion of the spectrum under review. Much of this spectrum is currently used either by the defence sector, or for a variety of non-harmonised applications across the EU.

- Some SMAs have established databases or other specialised software to help them to assess whether spectrum is being efficiently used. Examples include:
    - **Belgium:** CCRM (an independent non-profit association responsible for monitoring spectrum, partially sponsored by the NRA, the BIPT) has developed software to monitor and evaluate spectrum occupancy, currently from 30-1030 MHz. The system will in future be extended to cover the 30 MHz-5 GHz frequency range.
    - **Cyprus:** Electronic data is collected from licence applications and documents and from technical measurements to generate occupancy reports and statistical analyses.
    - **France:** Data is collected on licensed stations, frequency assignments and transmission sites. This information is maintained in a database managed by the SMA, the ANFr.
    - **Greece:** The SMA EETT gathers data on licensed apparatus and base stations every six months along with population and geographic coverage for national networks, but not all of the information is in electronic format.
    - **Ireland:** Data on licensing trends, e.g. for fixed links and PMR, is maintained but is not made publicly available.
    - **Lithuania:** Information on licensed transmitting stations is maintained, but no data on spectrum usage is collected.
    - **Luxembourg:** Maintains a register of spectrum licensing.
    - **Netherlands:** A national frequency register (NFR) is available on the NRA web site (in Dutch and English) which contains licence details for all of the services currently included in EFIS. This does not include most public sector or private sector (individually licensed) use as the Netherlands does not currently make information on these services public (either through EFIS or the NFR) due to legal concerns about privacy.
    - **Poland:** All data concerning licences is stored electronically, including location, equipment type, frequencies, radiated power, antenna characteristics and other relevant parameters.

- **Portugal:** Data is held on the number of users and the number of radio licenses, along with parameters such as level of field strength, bandwidth, signalling tones (for PMR) and emission frequencies.
- **Slovenia:** Data is held on licensing, but not on spectrum usage.
- **Spain:** A database managed by the Ministry includes administrative and technical data on licensed stations, and is used for planning when the Ministry receives an application. The database includes public networks, PMR, fixed links and fixed satellite stations. There is however no information on coverage area or on number of users (only numbers of stations).
- **UK:** A register of all tradable licences is maintained, which includes frequencies, locations and other technical details

A number of SMAs explicitly stated that they do not maintain any electronic data for the purpose of assessing efficient use of spectrum. These included Austria, Denmark (although we note that Denmark does have a publicly available frequency register), Germany and Sweden.

7.4 Requirement for additional data to support the inventory

We believe that it would be helpful for the Spectrum Inventory process if EFIS were to take up the 14 category taxonomy that we adopted for this study (see Annex 3).

Our analysis of the data gathered from the stakeholder interviews suggests that a good indication of the comparative utilisation efficiency of each frequency band can be obtained by gathering answers to a limited set of specific questions related to usage data. This information could be sought as part of the existing EFIS update process (by adding additional information fields to the existing input template), or by requesting Member States to check and update the inventory data on a periodic basis. The additional information would comprise the following:

- **Utilisation:** Number of installations, licences, base stations, mobile terminals, broadcast multiplexes and/or transmitting stations (specific data depending on the application). For PMSE applications, an indication of how frequently used (e.g. number of annual deployments).
- **Where used:** The percentage of population coverage, the number of locations where spectrum is in use, or the extent of geographic use (local, regional or national, depending the application).
- **Demand trend:** Declining, stable, low growth, or high growth.
- **Technology:** Reference to the relevant interface standard (where this is present in EFIS) or a brief description of the technology deployed (e.g. analogue or digital). Details of specific technology variants deployed should also be provided in cellular mobile and terrestrial broadcast bands.

7.5 Analysis of Technical Spectrum Efficiency

Although we found wide variations in the scope and quality of information available for different applications and between Member States (see Section 7.3), we believe we have identified sufficient information to make a reasonable assessment of technical efficiency in many cases. We note however that there is a sizeable quantity of spectrum in the range under review where there is not sufficient information to make such an assessment.

We have analysed the data that we gathered from our desk research and stakeholder discussions and used it to estimate the relative efficiency of spectrum use in each identified frequency band across the EU. To facilitate comparison across the EU, a number of common frequency bands have been identified, largely based on the existing European Common Allocation table and reflecting as far as practical any European or global harmonisation of frequency bands for specific applications. The list of frequency bands is presented in Table 20, along with an indication of the main use(s) currently within the EU.

Table 20: Common frequency bands identified

Freq (MHz)	Main use(s)
173-230	Broadcasting (Band III). Limited use for digital TV, DAB, PMR. and medical telemetry Widely used for PMSE.
380-400	PPDR band. Lower 2x5 MHz used in most Member States for PPDR (TETRA)
400-401	Mobile satellite services
401-406	Meteorology and ultra-low power medical implants
406-406.1	Satellite EPIRBs
406.1-410	PMR, defence systems
410-430	PMR / PAMR (harmonised mobile band in most of EU)
430-433.05	Defence systems, PMR, amateur
433.05-434.79	Harmonised SRD Band
434.79-440	Defence systems, PMR, amateur
440-446	PMR, Defence Systems
446-446.2	Licence exempt PMR (PMR446) – harmonised band
446.2-450	PMR, Defence Systems
450-470	PMR / PAMR (Harmonised Mobile Band in most of EU)
470-608	Broadcasting (TV), PMSE (wireless microphones)
608-614	Broadcasting (TV), Radio Astronomy, PMSE (wireless microphones)
614-790	Broadcasting (TV), PMSE (wireless microphones)
790-862	Harmonised Mobile Band (IMT), some residual analogue TV and PMSE
862-863	Government use

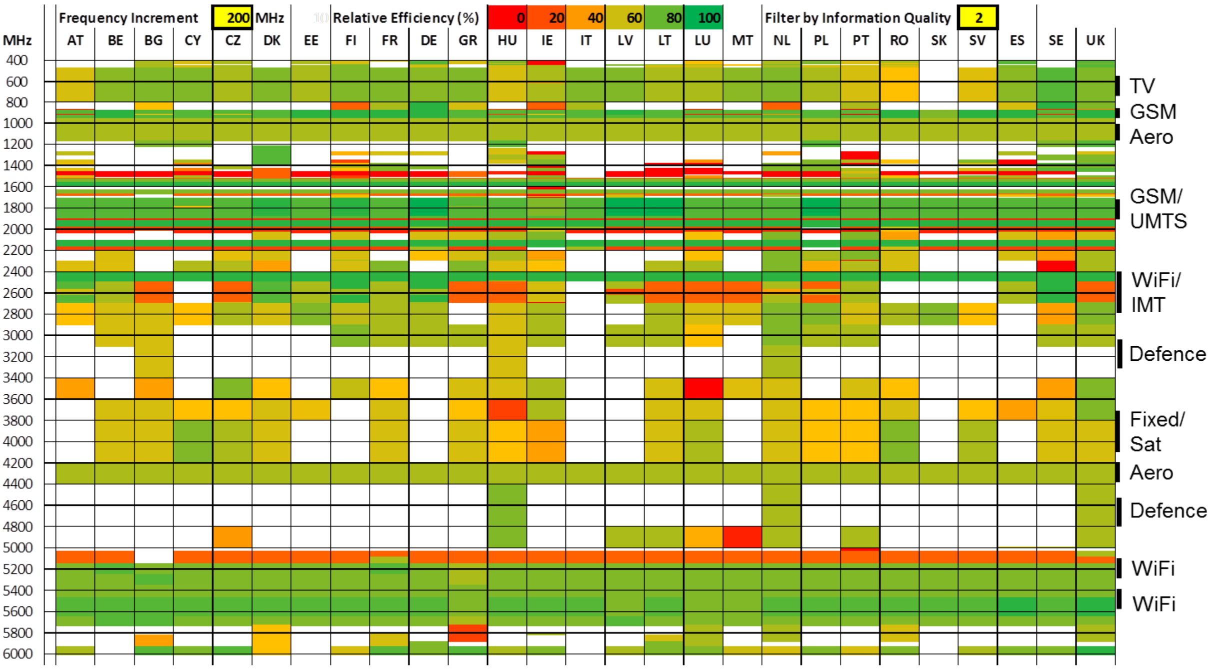
Freq (MHz)	Main use(s)
863-870	Harmonised SRD Band
870-873	Defence systems, PMR
873-876	Defence systems, PMR
876-880	GSM-R (EU harmonised band)
880-915	Harmonised Mobile Band (GSM, IMT)
915-918	Defence systems, PMR
918-921	Defence systems, PMR
921-925	GSM-R (EU harmonised band)
925-960	Harmonised Mobile Band (GSM, IMT)
960-1164	Global Aeronautical Band
1164-1215	Galileo / Glonass RNSS / Aeronautical Radars
1215-1240	GPS GNSS
1240-1260	Glonass RNSS
1260-1270	Galileo RNSS
1270-1300	Galileo RNSS / Wind Profilers
1300-1350	Aeronautical radars, Defence systems
1350-1375	Harmonised fixed link band (usually paired with 1492-1518)
1375-1400	Harmonised fixed link band (usually paired with 1427-1452)
1400-1427	Radio Astronomy (passive) – all emissions prohibited
1427-1452	Harmonised fixed link band (usually paired with 1374-1400)
1452-1479.5	Former T-DAB Broadcasting band, currently unused in most of EU
1479.5-1492	Former S-DAB Broadcasting band, currently unused in most of EU
1492-1518	Harmonised fixed link band (usually paired with 1350-1375)
1518-1525	Limited defence and fixed link use; possible extension band for mobile satellite service (MSS)
1525-1559	Satellite: MSS downlinks (paired with 1626.5-1660.5)
1559-1591	Galileo / GPS GNSS
1591-1610	Glonass RNSS
1610-1610.6	Radio Astronomy
1610.6-1613.8	Radio Astronomy
1613.8-1621.35	Satellite: Globalstar MSS uplinks (paired with 2483.5-2500)
1621.35-1626.5	Satellite: Iridium MSS uplinks / downlinks
1626.5-1660.5	Satellite: MSS uplinks (paired with 1525-1559
1660.5-1670	Radio Astronomy
1670-1675	Radio Astronomy / Meteorology
1675-1690	Meteorology

Freq (MHz)	Main use(s)
1690-1700	Meteorology
1700-1710	Meteorology / Fixed Links
1710-1785	Harmonised mobile band (GSM, IMT)
1785-1800	PMSE / SRDs: Digital Wireless microphones
1800-1805	Not currently in use in most of EU
1805-1880	Harmonised Mobile Band (GSM, IMT)
1880-1900	DECT cordless phones – harmonised band
1900-1920	Harmonised mobile band (IMT TDD)
1920-1980	Harmonised mobile band (IMT uplinks)
1980-2010	Harmonised MSS band (uplinks)
2010-2025	Harmonised mobile band (IMT TDD)
2025-2110	Space operations, fixed links, defence systems, PMSE
2110-2170	Harmonised mobile band (IMT downlinks)
2170-2200	Harmonised MSS band (downlinks)
2200-2290	Space operations, fixed links, defence systems, PMSE
2290-2300	Defence systems. PMSE, radio astronomy
2300-2400	Defence systems, PMSE. Potential future IMT band
2400-2483.5	WiFi and other licence exempt applications
2483.5-2500	Globalstar MSS downlink. New global primary allocation to radiodetermination service (WRC-12)
2500-2570	Harmonised mobile band (IMT uplinks)
2570-2620	Harmonised mobile band (IMT TDD)
2620-2690	Harmonised mobile band (IMT downlinks)
2690-2700	Radio Astronomy (passive – all emissions prohibited)
2700-2900	Aeronautical Primary Radars
2900-3100	Maritime Radars (land and ship borne)
3100-3400	Defence Systems, PMSE, some PPDR use
3400-3410	Defence systems, some BWA, harmonised mobile band (IMT)
3410-3600	Harmonised mobile band (IMT). Legacy BWA, defence and PMSE use
3600-3800	Fixed satellite (downlinks): 48 satellites for global communications within Europe.
3800-4200	Fixed links / Fixed satellite (downlinks):48 satellites for global communications within Europe
4200-4400	Radio Altimeters (global allocation)
4400-4500	Defence Systems
4500-4800	Defence Systems
4800-4940	Defence Systems

Freq (MHz)	Main use(s)
4940-4990	Defence Systems, PPDR. Radio Astronomy
4990-5000	Defence Systems, Radio Astronomy
5000-5030	Satellite: Galileo feeder links
5030-5090	Aeronautical: MLS – not currently used in most of Europe
5090-5150	Aeronautical: MLS – not currently used in most of Europe. Potential future aeronautical telemetry band
5150-5250	WiFi, defence systems
5250-5350	WiFi, defence systems
5350-5470	Airborne weather radars (global allocation)
5470-5650	WiFI, ground based weather radars
5650-5725	WiFi
5725-5795	RTTT, low power BWA
5795-5815	ITS, low power BWA
5815-5875	Low power BWA
5875-5905	ITS, Fixed Satellite uplinks
5905-5925	Fixed Satellite uplinks
5925-6425	Fixed links / Fixed satellite (uplinks)

Figure 9 provides an overview of the relative technical spectrum efficiency across the frequency range 400 MHz to 6 GHz. The colours indicate the relative value of the overall efficiency indicator, obtained by combining the four individual efficiency criteria (utilisation, demand growth, technology and geographic). The rating for each band in each country is compared to the highest overall rating in all bands and all countries, which is defined as 100%. Red corresponds to 0%, which effectively means that the band is not in use and is unlikely to be brought into use in its current form. Note that results are shown only for those bands where there is at least a moderate level of information available, i.e. where the information quality score in Figure 8 is at least 2.

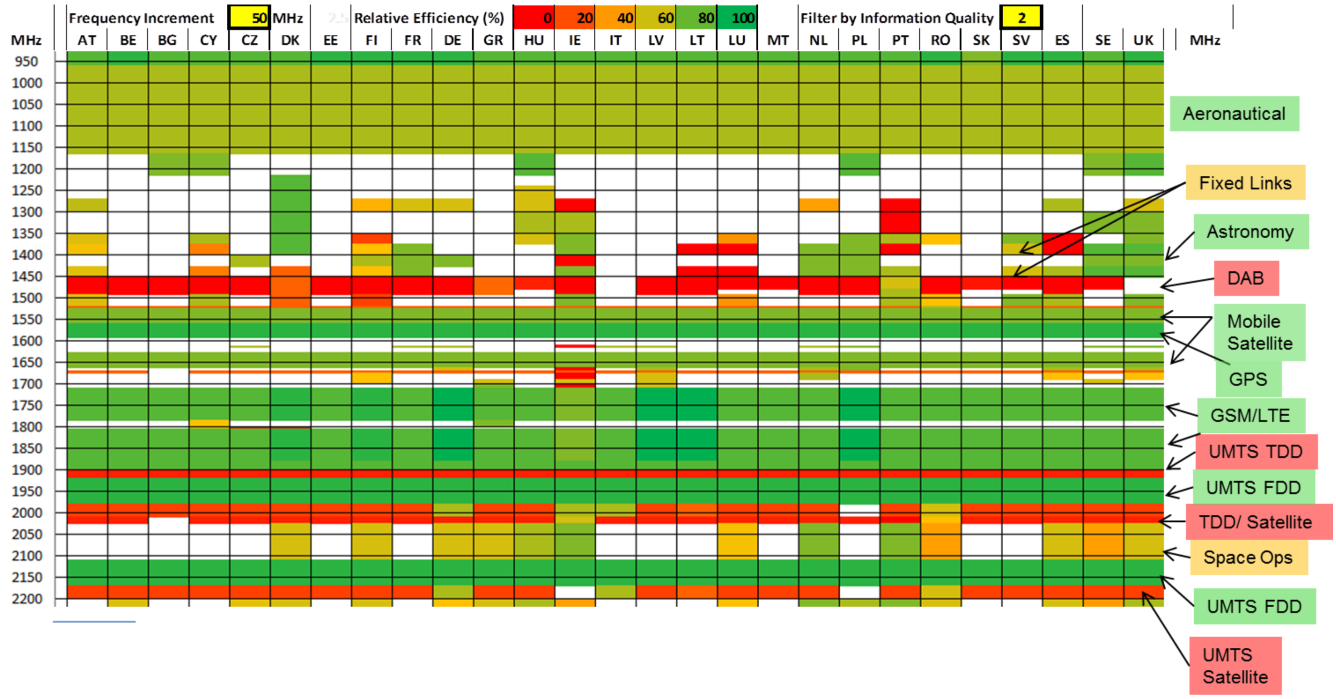
Figure 9: Comparison of technical efficiency, by frequency range and Member State



It can be seen that whilst the TV broadcast and public mobile bands (GSM/UMTS/IMT) are generally efficiently used, there are variations from Member State to Member State. This reflects differences in the progress made on digital switchover and on the number of digital multiplexes that have been launched in the case of the UHF TV band, and on differences in the extent to which 2G spectrum has been migrated to 3G technology in the former GSM bands.

Some bands are apparently unused throughout most or all of the European Union, appearing as horizontal red bars in the diagram. Figure 10 and Figure 11 show the relative efficiency of bands in the 1 – 5 GHz range in more detail.

Figure 10: Comparison of technical efficiency in the 960 MHz – 2200 MHz range

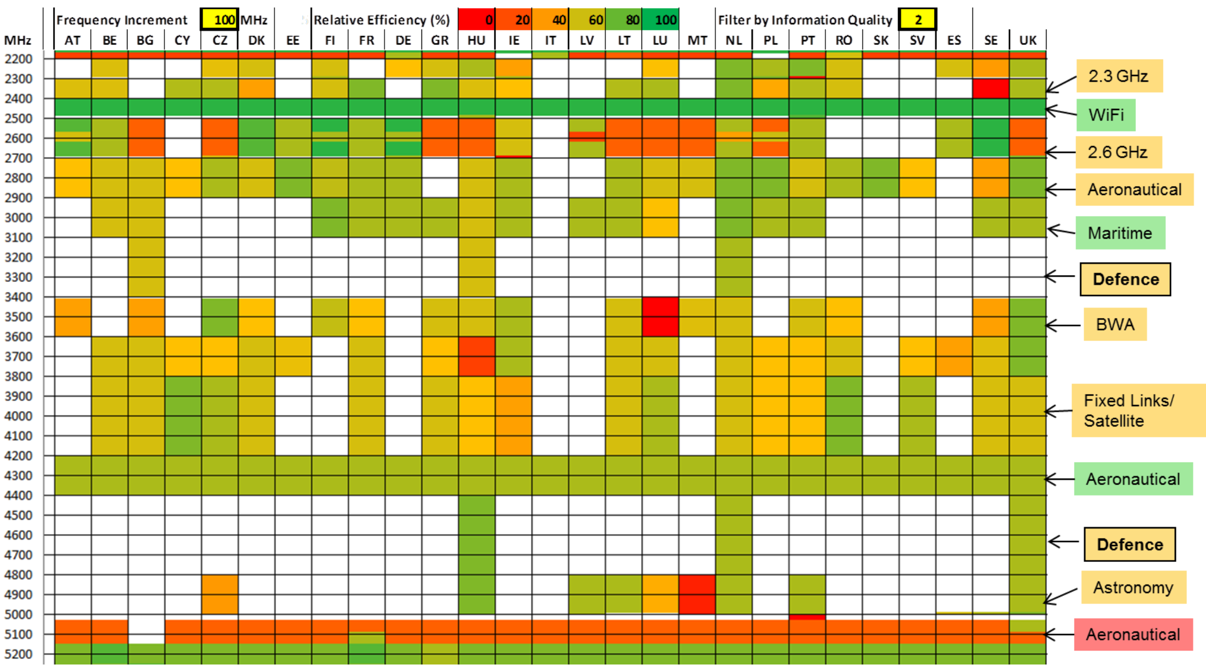


Here we can clearly see that the spectrum identified for terrestrial TDD and mobile satellite elements of IMT-2000 in the 2 GHz region remains largely unused, 20 years after these allocations were made at the 1992 World Radio Conference. Similarly, the L-band allocation to T-DAB (1452-1492 MHz) remains unused throughout most of the EU, with no active DAB deployments remaining in the band. The situation in the fixed link bands between 1350 MHz and 1527 MHz varies from country to country, with heavy use in the UK and France but no use at all in Spain or Lithuania.

Although detailed information on the usage of the mobile satellite bands in the 1.5/1.6 GHz region is not publicly available due to commercial confidentiality, discussions with stakeholders have indicated that these bands are extensively used across Europe, particularly by the aeronautical and maritime sectors, and that there is significant growth in demand for wideband data, e.g. via Inmarsat's Broadband Global Area Network (BGAN), which is used on land. The service is also used by the PPDR sector in remote areas or where terrestrial networks have failed. The satellites used to deliver the BGAN service deploy over 200 spot beams globally with a 4-colour frequency re-use pattern in high traffic areas, in order to maximise network capacity. An additional satellite (Alphasat) is due to be launched in 2013 as a joint venture between Inmarsat and the European Space Agency, operating in the current 1.5/1.6 GHz band plus additional adjacent spectrum (1518-1525 MHz and 1670-1675 MHz), to provide additional capacity across Europe, the Middle East and Africa.

Whilst we have good information on the use of the global aeronautical band immediately above 960 MHz, information on the bands between 1164 and 1525 MHz is incomplete or inconsistent (with the exception of the DAB band mentioned above and some of the GNSS bands), making it difficult to assess properly how efficiently these bands are being used at a European level. We understand however that there is extensive deployment of primary radars for civil and military aviation in the 1164 – 1350 MHz range across the EU.

Figure 11: Comparison of technical efficiency in the 2.2 GHz to 5.2 GHz frequency range



In this case, the lack of information relating to the mainly military spectrum in the 3.1 - 3.4 GHz and 4.4 - 5 GHz ranges is particularly apparent, as is the current lack of use of the MLS band (5030 - 5150 MHz) across most of the EU. We note however that the latter band has recently been allocated globally to the aeronautical mobile service, and the upper part of the band (above 5091 MHz) is planned for deployment of airport surface wireless communications as part of the European SESAR initiative.[69] The lower part of the band is under consideration for future deployment of aeronautical telemetry,

69 Single European Sky Air Traffic Management Research.

including command and control of unmanned aerial systems. There are also a small number of gateway earth stations for the Globalstar mobile satellite network in the upper part of the band.

There are significant variations in the extent to which much of the other spectrum in this range is used. In some cases (e.g. the 2.6 GHz IMT band) this reflects differences in the timescales for licensing the band across the EU; in others the decline of legacy services (e.g. fixed links in the 3.8 - 4.2 GHz bands) or the failure of new services to succeed in the market (e.g. BWA services in the 3.4 - 3.6 GHz band). Note also the significant differences that exist in the utilisation of the 2.3 GHz band, which has been identified by the ITU as a candidate band for IMT mobile services. It is unlikely that this band could be adopted as a harmonised band in Europe, given its importance for other applications in countries such as France and the UK, although it could be adopted on an individual country basis as equipment already exists for other international markets.

In conclusion, we have identified a number of bands where currently there is either no use at all, or substantial under-utilisation in most Member States. These include, for example:

- 1.4 GHz former DAB band (40 MHz) – already under consideration for potential future mobile broadband use.
- 2 GHz TDD and MSS bands (95 MHz) – remain unused in most countries 20 years after being allocated.
- 5 GHz MLS band (120 MHz) – little or no MLS use, but new aeronautical mobile services are planned.
- 3400 - 3800 MHz (400 MHz) – formerly used for BWA networks that have failed to gain market share in most EU countries. Parts of the band are used for satellite links, including Inmarsat feeder links, at specific locations. This limits the use of the band for BWA in adjacent areas. For example, much of northern Holland is restricted in order to provide the necessary protection for an Inmarsat gateway station.
- 3800 - 4200 MHz (400 MHz) – formerly used for point-to-point links, but use has declined due to migration to fibre and higher frequency bands. There is continued use by fixed satellite terminals, but these should be capable of sharing with other terrestrial services on a co-ordinated basis.
- 5725 – 5875 MHz (150 MHz). Licence exempt / light licensed band identified for BWA deployment, but little or no take-up in most Member States.

In other cases, usage varies significantly between Member States, limiting the scope for future harmonisation. Consider:

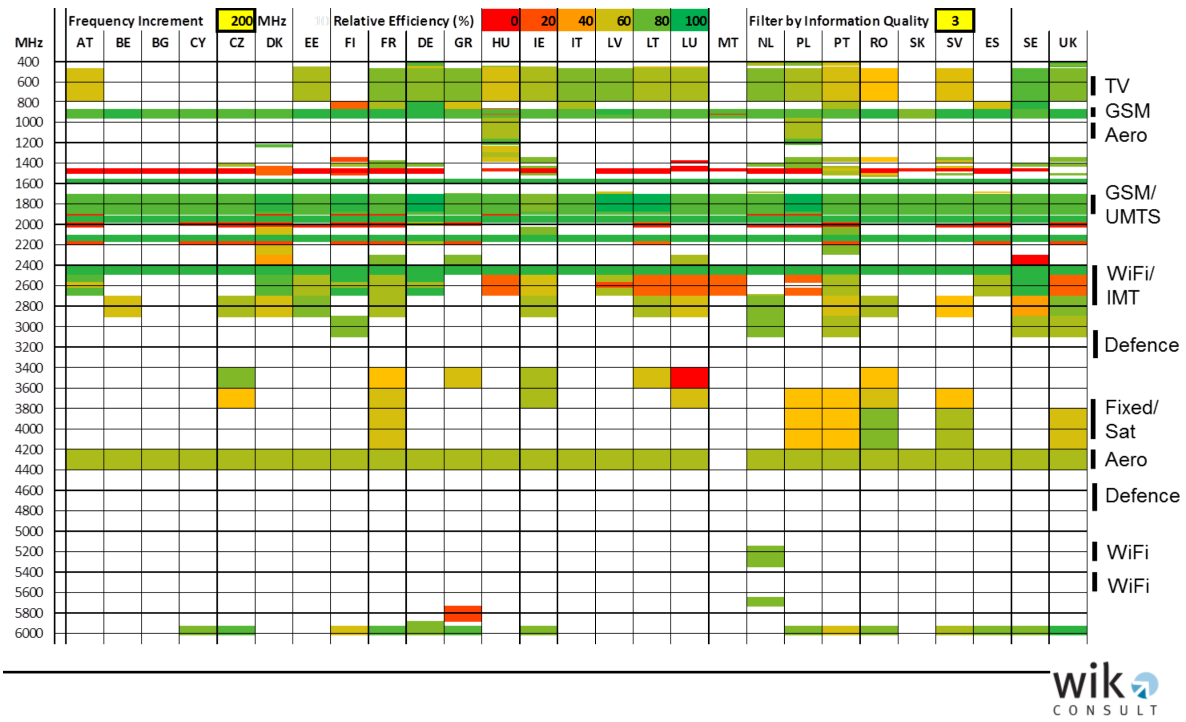
- PMR bands (406 - 470 MHz)

- fixed link bands around 1.4 GHz
- aeronautical radar band at 2.8 GHz
- 3.1 - 3.4 GHz and 4.4 - 4.8 GHz (mainly defence use).

7.6 Information Quality Caveat

The above results include a number of bands where the quality of information available has been categorised as “moderate”, which generally means there is sufficient information to make a judgement on most of the efficiency criteria, but not all. These bands are shown as amber in figure 6 and are subject to a greater degree of uncertainty than those bands where the information quality has been categorised as “good”. Limiting the efficiency analysis to the latter significantly reduces the number of bands where a conclusion can be reached on the relative efficiency in individual Member States. However, the lack of utilisation in the 1.4 GHz (DAB) band and the 2 GHz TDD and MSS bands across much of Europe is still clearly apparent.

Figure 12: Comparison of technical efficiency, by frequency range and Member State, where good information is available



Annex 1: Estimates of the economic value of spectrum

In this Annex, we summarise data on spectrum value in Europe for various frequency bands. We present data for the following measures of economic value:

- Auction prices – a measure of the incremental value of the spectrum.
- Opportunity cost estimates – another measure of the incremental value of the spectrum.
- Economic welfare estimates – a measure of average and incremental values.

We express value in units of €/MHz/pop. In some cases, we compare values using an index, with the base as shown in each table.

We also considered whether several other measures of economic value or activity such as revenues, GDP and employment, could be used and concluded that:

- Revenues on their own are not an appropriate measure of the economic benefits of different uses of spectrum. In fact, their use could be highly misleading. It could lead to a bias towards services that have high revenues largely as a result of having high costs of provision, but not necessarily high benefits for either producers or consumers.
- GDP is an incomplete measure of economic benefits.[70] For example, there is no accounting for the benefits to individuals from different uses of their time other than paid work. All time use that generates additional GDP is counted as a benefit, even if it reduces leisure time and potentially makes people feel worse off. Nonetheless, the GDP of an application is more informative than revenues because payments for inputs other than labour and capital are netted out.
- Employment is a very partial measure of economic benefits. It takes no account of the incomes that individuals or companies earn, or of the value of leisure time. We are not aware of any estimates of the employment impact of changes in spectrum allocations, unlike estimates of changes in economic welfare.

Economic welfare – measured as the sum of consumer and producer surplus – is the most appropriate measure of economic value, but it can be difficult to measure. There are some shortcuts to producing estimates of consumer surplus (which is typically much larger than producer surplus) that use revenue estimates and estimates of demand elasticities. Whilst these are likely to give conservative values, they should be sufficient in situations where we are looking for differences only to an order of magnitude (i.e. a factor of 10).

70 The limitations of GDP measures are discussed in for example "Report by the Commission on the Measurement of Economic Performance and Social Progress", Professors Stiglitz, Sen and Fitoussi, A report for the French President, 2008.

Using data reported in this Annex, we have developed an index of the relative value of different frequency bands in different uses. Ideally, we would have a function showing how value varied by quantity of spectrum for each frequency band/use combination; however, this is not feasible because of insufficient data. The data that is reported shows considerable variation in values within a frequency band/use combination, and it is for a variety of measures. Given all the many approximations that are necessary to bring together the data, we have focussed on order of magnitude differences between values for different use and bands.

In this Annex, we report both average and incremental values. Average values across all frequencies used by a service or for a specific frequency band are less useful than incremental values that apply when there is a change in the amount of spectrum allocated to a service. We also place more weight on recent value estimates/observations, as these reflect the best information that we have available to make decisions about the future.

For each service category we have derived values as follows:

- Public mobile: Evidence from auctions and economic value estimates suggests that the value of spectrum for public mobile services is much higher than for other applications (except for RFIDs and WiFi) by one if not two orders of magnitude. In the section on auctions, we provide a high level view of how value declines by frequency range. These differences arise from the technical characteristics of the spectrum and from the relatively small amounts of spectrum below as compared with above 1 GHz, so the differences can be expected to persist over time. The evidence on the rate of decline in value by frequency range is not consistent (partly because the comparisons are for different amounts of spectrum in different countries at different points in time), and there is considerable uncertainty about relative values in future.
- Business radio: This service only operates in harmonised bands up to 1 GHz; however, we have extrapolated values up to 3 GHz based on the reduction in coverage at the these higher frequencies. Estimated opportunity costs are similar to those for public mobile services, but auction values and the average economic value estimates suggest the average and incremental value of spectrum for business radio could be around a tenth that for public mobile services. We have taken values towards the bottom end of this range (of 0.1-1).
- Terrestrial television (TV): Studies on the digital dividend suggests a ratio of at least 10:1 for the value of UHF spectrum allocated to mobile broadband rather than TV though average economic values indicate a ratio closer to 2:1. We would expect the ratio to grow in the future, as TV services are increasingly consumed on-demand over IP platforms and via platforms offering sufficient capacity to deliver HD and 3D formats (i.e. cable and satellite).

- Fixed links: Opportunity cost and auction data consistently show spectrum below 1 GHz for this application is valued at one hundredth or less the value of spectrum allocated to public mobile services, i.e. at 0.005 - 0.01 compared with an index value of 1.0 for mobile. Demand for fixed links in bands between 1 and 6 GHz is in decline as a result of increased fibre deployment and growing demands from mobile operators for short distance, wide bandwidth links (at higher frequencies). For these reasons, we have assumed values of 0.001 at frequencies above 1 GHz. At UHF frequencies where telemetry systems are deployed, licensees pay the same spectrum prices as for business radio in the UK, which suggests that higher values may apply for small amounts of spectrum below 1 GHz.

- PMSE: Opportunity cost estimates point toward the highest values in bands below 1 GHz. We have used similar relative values as for fixed links, as there are no direct estimates of value for this application.

- Satellite (civil): The opportunity cost estimates for satellite services suggest an incremental value of spectrum for fixed satellite services that is similar to that for fixed links. The average economic value estimates for satellite services are around 2-5 times higher than that for fixed links, with values for broadcasting and MSS being at the high end across a range of frequencies. In both cases, there is considerable uncertainty around the values, particularly as some of the satellite uses (e.g. satellite radio broadcasting) have yet to be proved commercially viable. We have therefore suggested values similar to those for fixed links in the 1-2 GHz range. There is a very small amount of spectrum used for satellite services in the 400 MHz range on a global basis. We have attributed a value of 0.1 to this use, although the value is highly uncertain.

- SRDs: The value here depends on the specific application and the amount of additional spectrum allocated. Estimates suggest average economic values are high, but we expect that incremental values will be less - particularly for those applications that use small amounts of spectrum (e.g. RFIDs). As with other applications, lower frequencies are regarded as more valuable than higher frequencies for SRDs because of their propagation characteristics. We have therefore given this application a value of 1 in frequencies below 1 GHz, and then used our judgement to reduce the value for higher frequency ranges.

- WDTS (WiFi): The average economic value estimates suggest a high value for this application deployed at 2.4 GHz comparable to that for public mobile services. It is possible that the value may decline with frequency range because of the greater capacity and declining coverage offered; however, given that WiFi is largely used indoors, coverage issues are less acute than for public mobile services. We have assumed a flatter profile for the application than for public mobile.

Based on this reasoning, we constructed Table 21, which gives a high level view of the relative incremental values of different bands and applications. We propose zero values in frequency ranges where the high cost of service deployment, technical barriers, or the limited bandwidth available mean the service would not be deployed.

Table 21: Index of incremental value/MHz/pop for harmonised allocations by application and frequency band

	400-600 MHz	600 MHz - 1 GHz	1-2.1 GHz	2.1-3 GHz	3-4 GHz	4-6 GHz
Cellular/BWA	0.01	1	0.5	0.1	0.01	0.001
Broadcasting (Terrestrial)	0.5	0.1	0.01	0.001	0	0
PMR/PAMR	0.1	0.1	0.01	0.01	0	0
Fixed links	0.1	0.1	0.005	0.001	0.001	0.001
PMSE[71]	0.1	0.1	0.01	0.001	0.001	0.001
Satellite (civil)	0.1	0	0.005	0.005	0.005	0.001
SRDs[72]	1	1	0.1	0.01	0.001	0.001
WTDS (WiFi)	1	1	1	1	0.1	0.1

Public mobile services for frequencies in the range 700 MHz to 1 GHz are denoted with a value of 1.0. Red colour coding indicates applications that require relatively little additional spectrum (typically less than 10MHz).

The remaining sections of this Annex report data on auction prices, opportunity cost estimates, and estimates of economic welfare.

Auction prices

Historic auction prices exist mainly for bands harmonised for public mobile services, although there are a few cases of auctions of other bands.

If we take the value in frequency range 600 MHz-1 GHz for public mobile services to equal 1, then we propose to use the following index values for other frequency ranges for mobile services:

- 400-600MHz: 0.01
- 600MHz – 1 GHz: 1
- 1-2.1 GHz: 0.5

71 Below 1 GHz, the applications are mainly wireless microphones and talkback. Above 1 GHz, wireless cameras and video links are deployed.
72 For SRDs below 1GHz, small amounts of spectrum (1-2 MHz) can be of high value.

- 2.1-3GHz: 0.1
- 3-4 GHz: 0.01
- 4-6GHz: 0.001 - Not known but likely very small

Note that it is assumed that any bands identified for public mobile services can be harmonised on a European basis so as to provide sufficient scale for low cost competitive equipment provision.

For other applications, index values of 0.001 have been achieved and do not appear to vary in a systematic way for bands below 6GHz. Index values are much smaller at frequencies above 6 GHz.

Public mobile bands

The following tables provide auction results for different groupings of auctions of frequency bands used for public mobile services in Europe. The average value and the range are reported for each frequency range. Table 22 is for all auctions from 1999 on and Table 23 is for all auctions from 2005 on. Auctions since 2005 are likely to be most relevant because mobile broadband, which is now the main driver of spectrum demand from public mobile services, barely existed before 2005.

In comparing the results for different frequency bands, it must be remembered that the amount supplied differs by band and between auctions, and so the data do not provide a “like for like” comparison of the value of bands. For example, supply is more constrained at lower frequencies which increases value all else being equal. Below around 700MHz[73], antennas size may become an issue for the small form factor of many mobile devices and so value declines for this reason. Above 700MHz the value revealed in auction derives from both the capacity and coverage offered by the frequencies[74], the vigour of competition in the auction and factors affecting market sentiment and expectations at the time of the auction. Nevertheless inspection of the tables shows some clear patterns:

- The frequencies in the 800MHz, 900 MHz and 2.1 GHz ranges have the highest average prices although there is considerable variation in price within each frequency range
- Prices paid for 450MHz, 2.3GHz and 2.6 GHz bands are much lower than those in the 800MHz - 2.1 GHz range, by around an order of magnitude
- Prices paid for 3.5 GHz and 3.7 GHz bands are lower by a further order of magnitude.

73 The precise break-point is not known but an engineering rule of thumb suggests that it is around 70-80% of the upper frequency used by the antenna.

74 See J Mardendahl and B Molleryd (2011) for an estimation of the capacity and coverage benefits of incremental spectrum that derive from cost savings and strategic value for operators with differing initial spectrum holdings. “Mobile broadband expansion calls for more spectrum or more base stations: analysis of the value of more spectrum and the role of spectrum aggregation”, International Journal of Management and Network Economics, Vol 2, No 2, 2011.

Table 22: Average prices paid in European auctions for spectrum in bands used for public mobile services (1999 on)

Frequency range	No. of data points	Average €/MHz/pop	Min. value	Max. value
450	2	0.0598	0.0103	0.1093
800	6	0.5862	0.4089	0.8144
900	11	0.2515	0.0049	0.7253
1800	9	0.1638	0.0048	0.4326
2100	21	0.7844	0.0742	4.5579
2300	1	0.0097	0.0097	0.0097
2600 FDD	13	0.0500	0.0011	0.1644
2600 TDD	9	0.0230	0.0025	0.0457
3500	7	0.0087	0.0004	0.0186
3700	1	0.0007	0.0007	0.0007
All IMT	80	0.3160	0.0004	4.5579

Source: Regulators' websites, Plum analysis

Table 23: Average prices paid in European auctions for spectrum in bands used for public mobile services (2005 on)

Frequency range	No. of data points	Average €/MHz/pop	Min. value	Max. value
450	1	0.0103	0.0103	0.0103
800	6	0.5862	0.4089	0.8144
900	8	0.2883	0.0193	0.7253
1800	6	0.1224	0.0048	0.2623
2100	11	0.2206	0.0742	0.4593
2300	1	0.0097	0.0097	0.0097
2600 FDD	13	0.0500	0.0011	0.1644
2600 TDD	9	0.0230	0.0025	0.0457
3500	5	0.0098	0.0004	0.0186
3700	1	0.0007	0.0007	0.0007
All IMT	61	0.1625	0.0004	0.8144

Source: Regulators' websites, Plum analysis

Other bands

The prices paid in recent European auctions for non-IMT bands classified by frequency range are summarised in Table 24. The prices paid are low relative to those for IMT bands – around an order of magnitude less than for the 3.5 GHz band.

Table 24: Prices paid in European auctions for spectrum in non-mobile bands (2005 onwards)

Frequency range	No. of data points	Average €/MHz/pop	Min.	Max.
< 1 GHz	4	0.0040	0.0005	0.0092
1-3 GHz	5	0.0071	0.0003	0.0147
3-6 GHz	0	Not applicable	Not applicable	Not applicable
6-15 GHz	2	0.0004	0.00002	0.0007
> 15 GHz	8	0.0003	0.00001	0.0014
All	19	0.0029	0.00001	0.0147

Source: Regulators' websites, Plum analysis

The details of the auctions and frequency ranges that underpin Table 24 and possible use of the auctioned bands are shown in Table 25.

Table 25: European auctions for spectrum in bands not used for public mobile services

Country	Frequency Range	Possible use	€/MHz/pop
Denmark	410-430 MHz	Land mobile	0.0020
Ireland	1785-1805 MHz	BWA	0.0024
Ireland	26 GHz	BWA	0.0014
Norway	1790-1800 MHz	BWA	0.0003
Norway	10 GHz	Fixed links	0.0001
Norway	11 GHz	Fixed links	0.0007
Norway	23 GHz	Fixed links	0.0005
Sweden	10.5 GHz	Fixed links	0.0003
Sweden	28 GHz	Fixed links	0.00001
UK	412-414 MHz/ 422-424 MHz (geographic limitations)	Business radio (possibly smart metering/smart grids)	0.0092
UK	542-550 MHz (Cardiff)	TV	0.0042
UK	758-766 MHz (Manchester)	TV	0.0005
UK	1452-1492 MHz 40 MHz	T DAB/multi-media broadcasts	0.0043
UK	1781.7-1785 MHz/ 1876.7-1880 MHz (GSM/DECT general bands)	Local wireless access	0.0137

Country	Frequency Range	Possible use	€/MHz/pop
UK	1785-1805 MHz (Northern Ireland)	BWA	0.0147
UK	10 GHz	Fixed links	0.00002
UK	28GHz	Fixed links	0.00001
UK	32 GHz	Fixed links	0.00001
UK	40 GHz	Fixed links	0.000001

Source: Regulators' websites, Plum analysis

Opportunity cost and AIP estimates

Opportunity cost estimates have been produced in the UK by Ofcom to provide the basis for setting spectrum fees in a wide range of frequency bands. We did not find any estimates of opportunity cost produced by other SMAs in Europe.[75]

A weakness in the opportunity cost estimates and prices that we report is that they based on are static rather than forward looking analysis (often based on a snapshot of demand and technology), and do not include any value of flexibility from holding spectrum (unlike auction values). In addition, some of the values are now rather old. Nonetheless, these prices are paid by users and so could be said to provide a lower bound on their willingness to pay for spectrum. Like the auction values, they are indicative but not determinative of relative value.

The following table provides information on the opportunity cost and the administratively determined prices (termed AIP and expressed as £/MHz on a national basis) for various frequency bands. The AIP value was usually though not always set at roughly 50% of an estimate of the opportunity cost of the spectrum. The AIP is relevant because it is actually paid, unlike the more theoretical opportunity cost value.[76] The values for the two IMT bands will be reset based on market benchmarks, once the auction of the 800 MHz and 2.6 GHz bands has concluded.[77]

Opportunity cost estimates have also been derived for spectrum used by PMSE but have not been applied. For PMSE uses, opportunity cost estimates were obtained for a wide range of bands. The highest (annual) value was for channel 69, the only spectrum nationally available for wireless microphones – £2.8m/MHz based on the potential alternative use of the band i.e. mobile broadband. Other significant values were obtained for the PMR UHF band – £220k-335k/MHz. Other bands had low values – below £30k/MHz. In all cases, values were determined by the value to the alternative use for the band (i.e. PMSE was not the highest value use of the band at the margin).

75 There are a few examples outside of Europe, however, such as Industry Canada.
76 Some opportunity cost estimates were calculated in 2004 while others have been determined more recently.
77 Para 1.9.4 http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/summary/combined-award-2.pdf.

AIP is also applied to radio-astronomy users, and again they pay AIP based on the highest value alternative use of the spectrum.[78]

The highest opportunity cost estimates are for VHF and UHF bands used by a variety of mobile services with a somewhat lower value given for TV use of the UHF band assuming that it was not possible to use this part of the band for another service (such as mobile broadband). As can be seen from Table 26, there is relatively little variation in value between the AIP values up to 2 GHz, no values in the 2-4 GHz range and then very low values for fixed links bands from 4 GHz on. AIP values for satellite earth stations are based on the AIP for fixed links.[79]

Table 26: UK Opportunity cost and AIP values – annual values/MHz

Band and service	Opportunity cost (£/MHz)	AIP[80] (£/MHz)	AIP Index 1=AIP for VHF/UHF private mobile radio
Aeronautical communications band (VHF)	£1.4m[81]	396k[82]	1
Maritime communications band (VHF)	620k	396k[83]	1
Business radio (VHF and UHF)	620k[84]	396k	1
UHF – if TV only permitted use	500k[85]	Not applied	Not applied
880-960 MHz – IMT	840k[86]	356.4k	0.9
1.8 GHz – IMT	840k[87]	277.2k	0.7
Fixed links bands – 4-15 GHz	7.5k[88]	2.2k (100 links)	0.006
Fixed links bands – above 15 GHz	-	0.9k (100 links)	0.002

Sources: Policy Evaluation Report: AIP, Ofcom 2009[89]; Indepen et al (2004)[90]

78 http://stakeholders.ofcom.org.uk/binaries/consultations/astronomy/statement/statement.pdf.
79 http://stakeholders.ofcom.org.uk/binaries/consultations/pricing06/summary/pricing06.pdf
80 Statutory Instrument, 2011, No 1128, The Wireless Telegraphy (Licence Charges) Regulations 2011. http://www.legislation.gov.uk/uksi/2011/1128/pdfs/uksi_20111128_en.pdf.
81 Aeronautical and maritime spectrum pricing, Indepen and Aegis (2007) http://stakeholders.ofcom.org.uk/market-data-research/other/spectrum-research/spectrumaip/.
82 http://stakeholders.ofcom.org.uk/consultations/licence-charges-2012/summary.
83 http://stakeholders.ofcom.org.uk/binaries/consultations/aip_maritime/statement/statement.pdf.
84 Values calculated in An economic study to review spectrum pricing, Indepen, Aegis and Warwick University (2004). http://stakeholders.ofcom.org.uk/market-data-research/other/spectrum-research/independent_review/.
85 This was derived from the traded value of capacity on a TV multiplex. This value may be very dependent on demand conditions at the time of the trade – 2005. The potential application of administrative incentive pricing to spectrum used for terrestrial TV and radio broadcasting, Indepen and Aegis for Ofcom, October 2005 http://www.ofcom.org.uk/consult/condocs/futurepricing/aipstudy.pdf.
86 Values calculated in Indepen et al (2004).
87 Values calculated in Indepen et al (2004).
88 Values calculated in Indepen et al (2004).
89 http://stakeholders.ofcom.org.uk/market-data-research/other/spectrum-research/policy_report/
90 http://www.ofcom.org.uk/research/radiocomms/reports/independent_review/spectrum_pricing.pdf

A study for the European Commission collected information on fees paid by mobile satellite operators for licences in Europe for the 2 GHz band.[91] This shows that the operators pay fees of at least €40m per year for access to 2x15 MHz across 22 Member States. This implies an annual value per MHz per pop of around €0.004 (population =300m and 2x15 MHz of spectrum has been assigned). To make a comparison with auction payments, this value needs to be converted to a discounted lump sum value. With a 10% discount rate, this implies multiplying by a factor of around 10, implying an average value for the 2 GHz band of €0.04/MHz/pop. This is around a twentieth of the auction values reported in Table 22 for the 2 GHz IMT band

Our estimates of the value of MSS spectrum reflect our best judgment, but we would acknowledge that there is substantial uncertainty about the value of MSS spectrum, especially in light of uncertainty about the future viability of the service. It is clear that the value of spectrum for MSS cannot be less than the licence fees that the operators pay, but we cannot exclude the possibility that the value might be considerably higher than their current payments imply.

Estimates of economic welfare

Estimates of economic value mainly based on economic welfare measures have been produced in various studies for Ofcom and at a European level. The results are summarised in this section.

In the case of services with large allocations these data do not give a reliable indication of the economic value that might be gained or lost as a result of a relatively small change in the amount of spectrum allocated to the service in question. We note also that the study by Europe Economics (2006) for Ofcom on the economic impact of radio spectrum use in the UK provided two measures of economic value. Consumer surplus was estimated at £42.4 billion compared to direct GDP contribution of £46.5 billion (see Table 27) and as can be seen the two measures give a similar indication of the relative value of difference uses to the same order of magnitude.

Table 27: Economic value of radio spectrum use in the UK Sector

	Consumer and producer surplus (£ bn)	GDP contribution (£ bn)
Public mobile	21.8	37.5
Broadcasting	12.3	7.5
Private mobile radio	1.2	1.5
Total	**42.4**	**46.5**

Note: GDP contribution is calculated by turnover of major radio spectrum using firms.

Source: Europe Economics

91 Study on MSS Authorisation Regimes and Authorisations in the EU Member States, Hogan & Lovells, 20 Feb. 2012 http://ec.europa.eu/information_society/policy/ecomm/doc/library/ext_studies/study_mss_auth_201203.pdf

The following three tables show estimates of the economic value of spectrum in a variety of uses. Comparing the values across the tables, it can be seen that RFIDs[92] and WiFi have the highest average economic value, followed by public mobile, broadcasting, PMR, satellite links and then fixed links (given current allocations). Further support for the high value of spectrum for licence exempt applications comes from a recent study which produced estimates of value on a global basis for WiFi and the use of white spaces for machine-to-machine communications.[93] It was estimated that the consumer surplus for Europe from the use of WiFi amounted to $20-30 billion USD p.a., which corresponds to an NPV of around €2.7/MHz/pop - 4/MHz/pop.[94] We caution again that average values may not be a good indicator of the incremental value of changing allocations.

The economic value of the use of 1452-1492 MHz in Europe for digital radio broadcasting (T-DAB and S-DAB) has been estimated as €8.6 billion;[95] however, this frequency range has been available for use by terrestrial and satellite broadcasting services for over 10 years, but it has not been used for this purpose,[96] suggesting the value is highly uncertain. The data in the following three tables show that, given current allocations, RFIDs and WiFi have the highest average economic value followed by public mobile, broadcasting, PMR, satellite links and then fixed links. However, it needs to be remembered that RFIDs require relatively little spectrum as compared with WiFI or mobile broadband. Also as we have already mentioned average values may not be a good indicator of the incremental value of changing allocations.

Table 30 shows there is a relatively wide range on the economic value estimates for wireless broadband - €0.51 to €7.01 per MHz per pop. Within the licensed applications, average values differ by a factor of 100. Also, in general applications using frequencies below 3 GHz have much higher economic value than those above 3 GHz. The general ordering of value is similar to that revealed by auctions and the AIP/opportunity cost values reported above.

Analysys Mason (2009) suggests that there will be substantial net economic benefits from reallocating the top of the band – 790-862 MHz – and possibly also the next 96 MHz (694-790 MHz) from TV to mobile broadband services on a harmonised basis across the EU.[97] They find the relative economic value of allocating one or both blocks

92 RFIDs require relatively little spectrum as compared with WiFI or mobile broadband, so high values do not imply a high spectrum demand.

93 The Economic Significance of Licence-Exempt Spectrum to the Future of the Internet, Richard Thanki for Microsoft, June 2012

94 Assuming a 10% discount rate and discounting over 15 years.

95 See the final FM 50 report “Future Harmonised Use of 1452-1492 MHz in CEPT” www.cept.org/Documents/fm-50/6130/FM50(12)075_Annex-4_Final-draft-ECC-Report-(consolidated*)*

96 This is unlike the situation in the US, where a commercially successful satellite radio service operates. In the US the common language, the poor coverage of radio stations outside urban areas (relative to Europe) and the lower population densities may all explain the greater popularity of satellite radio services in the US as compared with Europe.

97 http://www.analysysmason.com/PageFiles/13825/Analysys%20Mason%27s%20final%20report%20%27Exploiting%20the%20digital%20dividend%20-%20a%20European%20approach%27%2020090814.pdf.

of spectrum to mobile broadband rather than DTT is 10: 1 or more (depending on the scenario). Similarly, analysis in the US suggests that economic welfare would be enhanced if more UHF spectrum was reallocated from TV to mobile broadband services.[98]

A recent study by Capital Economics for Everything Everywhere estimated that deploying 4G LTE in the UK will increase consumer and producer surplus by around £0.9-1.4 billion annually. However, as the study's comparison is based on technology (i.e. 3G and 3.5 G vs 4G LTE), the linkage between spectrum use and calculated benefits is not clear. Thus the results cannot be considered a reliable estimate for the benefits of spectrum use.

Table 28: Average annual value of various uses and bands – UK (2006 prices)

Service	Frequencies	Value/MHz (£m – annual)	Value index 1= public mobile
Public mobile	900/1800/2100 MHz (360 MHz total)	60	1
Business radio	Various bands from 55 MHz to 466 MHz (Total 172 MHz)	7	0.12
Broadcasting – terrestrial	FM radio and UHF TV (Total 410 MHz)	26	0.43
Broadcasting – satellite[99]	2050 MHz at various frequencies in 11-13 GHz	0.85	0.06
Satellite links	Various bands from 3.6 GHz to 15 GHz (Total 2450 MHz)	1.1	0.02
Fixed links	Various bands from 1.4 GHz to 38 GHz (Total 9934 MHz)	0.4	0.01

Source: Plum and Aegis analysis, Economic impact of the use of radio spectrum in the UK, Europe Economics, 2006[100]

98 The Brattle Group. The Need for Additional Spectrum for Wireless Broadband: The Economic Benefits and Costs of Reallocations. http://www.brattle.com/_documents/UploadLibrary/Upload809.pdf.
99 We assumed £1,700m of the total £12,269m attributed by Europe Economics to broadcasting was attributable to satellite services based on Europe Economics' estimates of the consumer surplus associated with satellite services.
100 http://www.ofcom.org.uk/research/radiocomms/reports/economic_spectrum_use/economic_impact.pdf

Table 29: Average NPV and annual economic value for RFIDs and WiFi (UK)

Application	Frequencies	Value/MHz (£m – 20 year NPV to 2026)	Value/MHz (£m – annual)[101]	Value index public mobile = 1
RFIDs	863-870 MHz band (assumed 4 MHz available)	2500[102]	180	3
WiFi and others	2.4 GHz band (assumed 83 MHz available)	1320	93	1.5

Source: The economic value of licence exempt spectrum, Indepen et al for Ofcom, December 2006

Table 30: Summary of studies estimating the economic value of mobile broadband in Europe

Study	Date	Finding	Economic value of mobile broadband – NPV €/MHz/pop
Analysys Mason for the Greek Ministry of Transport, Infrastructure and Networks	2012	Net benefits from assigning 60 MHz in the the 800 MHz band to mobile services is €3.5bn.	5.45
Plum Consulting for Qualcomm and Ericsson	2011	Net benefits from the harmonisation and use of 1.4 GHz band for a supplemental downlink for mobile broadband services In Europe could generate economic benefits worth as much as €54 billion.	0.7-2.7
Analysys Mason/ Dotecon/ Hogan and Hartson for the European Commission	2009	Net benefits of 72MHz digital dividend spectrum as between €17 billion to €43 billion (allowing for costs of digital switchover).	0.5 to 1.47
Hazelett and Munoz	2008	UK 3G auction generated US$35 billion in consumer surplus from auction of 140MHz of spectrum.	4.57
Analysys Mason/Hogan and Hartson for ARCEP	2008	Private value of 72MHz digital dividend spectrum in France for mobile broadband is €26.2 billion.	6.82
Analysys Mason for Dutch Ministry of Economic Affairs	2008	Private value of 72MHz digital dividend spectrum for mobile broadband in the Netherlands is €0.5 to 6.9 billion.	0.51 to 7.01

101 We assume a 3.5% discount rate to convert NPV to a constant annual value.
102 We have taken estimates for the low demand scenario as the take-up of RFIDs has not been as fast as assumed in this report. See ECO report in the Dynamic Evolution of the RFID Market, January 2010.

Study	Date	Finding	Economic value of mobile broadband – NPV €/MHz/pop
Spectrum Value Partners for Ericsson, Nokia, Orange, Telefonica and Vodafone	2008	Private value for Europe 80MHz of digital dividend spectrum us €111 billion to €180 billion.	2.79 to 4.52
SCF for Deutsche Telekom	2007	Estimate the direct benefit of allocating 40MHz spectrum for wireless broadband as €101 billion and the benefit of 240MHz spectrum to wireless broadband as €463 billion.	3.88 to 5.07
Analysys Mason/ Dotecon/Aegis for Ofcom	2006	Private value (consumer + producer surplus) of 56MHz of digital dividend spectrum (800 MHz) for mobile broadband in UK is £2.5 billion.	1.08
Europe Economics for Ofcom	2006	Net economic benefit of mobile telephony in the UK in 2006 is £22 billion.	1.61

Annex 2: Background information on benchmark countries

In this annex, we provide background information on a number of countries (in Europe and around the world) that are benchmarking the efficiency of their spectrum allocations and/or usage.

A2-1 Australia

A2-1.1 Overview

The Australian Communications and Media Authority, ACMA, is the public body that is responsible for radiofrequency spectrum management in Australia. The ACMA's current spectrum policy and management plans are given in its Five Year Outlook 2012-2016.[103] These outlooks have been produced every year since 2008 and include an assessment of the current use of spectrum, demand trends, international developments and actions the ACMA plans to undertake over the forthcoming five years.

In 2011, the ACMA began its mobile broadband project in response to the rapidly growing demand for spectrum. The aim of the mobile broadband project is to stimulate further discussions with stakeholders in order come up a forward work plan for spectrum planning, policy and allocation activities that can be implemented in 2013. The ACMA estimated that up to 300MHz of additional spectrum will be required to support mobile services by 2020, with up to 50% of this bandwidth being required by 2015.[104] To achieve this goal, there are concrete plans that are underway for specific bands between 700MHz and 3.4GHz. In particular, the additional frequencies may come from:

- The top part of the digital dividend which will be used to supplement the frequencies in the 850 MHz band, which together with further reorganisation of the band could give mobile services 30 MHz of extra spectrum.
- Up to 83 MHz could be freed up in the 1.5 GHz band
- Up to 200 MHz could be freed up in the 3.4GHz band

A2-1.2 Current plans and imminent future actions

In parallel to the consultation around which the mobile broadband project revolves, there are steps that are being taken reorganise and re-issue mobile and broadband wireless access licences in the 850 MHz, 900 MHz, 1800 MHz, 2 GHz and 2.3 GHz

103 http://www.acma.gov.au/WEB/STANDARD/pc=PC_410352.
104 http://www.acma.gov.au/webwr/_assets/main/lib312084/ifc13_2011_toward_2020-future_spectrum_requirements_errata.pdf.

bands that will expire in the next few years.[105] The reissue process is under way and in some cases will be completed in 2012. The ACMA will auction frequencies in the 700 MHz and 2.5 GHz band in the near future. Table 31 lists the bandwidths in this band that will be available through the auction.

Table 31: Frequencies in 700MHz and 2.5GHz to be auctioned in 2012-2013

Band	Frequency range (MHz)
700MHz	703-748, 758-803
2.5GHz	2500-2570, 2620-2690

The 803 MHz-960 MHz band is under review. Possible changes in this frequency range are:

- Expanding the 850 MHz band (825-845/870-890 MHz) to include frequencies in the ranges 803 MHz – 825 MHz and 845 MHz – 870 MHz
- This could yield up to 47 MHz, some of which could be made available for commercial mobile broadband services and some for mobile broadband for public safety agencies.
- Reducing allocations to some existing services – see the table below.

In the 900 MHz band, a reorganisation of the band is under consideration to improve the technical efficiency of the band by reorganising it into blocks of 2x5MHz. Present assignments to mobile operators are paired bandwidths of 8.4MHz. The review of these proposals and development of new arrangements are expected to conclude in 2Q14.

Table 32: Present use of frequencies in the 850 MHz and 900 MHz bands

Frequency range (MHz)	Present use
820-825, 865-870	Land mobile service
825-845, 870-890	Cellular mobile telephone services
845-865	Fixed service, cordless telephone service
890-915, 935-960	Cellular mobile telephone services
915-935	Fixed services (single-channel and low-capacity), radiolocation, digital short-range radio, wireless audio transmitters, spread spectrum systems and radio frequency identification transmitters, Industrial, Scientific and Medical Applications

105 http://www.acma.gov.au/WEB/STANDARD/pc=PC_410352.

A2-1.3 Future plans

Plans are also being drawn up to free up spectrum in the 1.5GHz and 3.4GHz band for use in the provision of mobile broadband service. Due to the uncertainty of the international environment on the allocation of these bands, the ACMA's review process of the frequencies is also at a very early stage.

A2-1.3.1 1.5GHz band

For the 1.5GHz band, the ACMA proposed two new planning arrangements in the band for the provision of mobile services in 2012. These are the use of frequencies in the range 1427.9 MHz – 1462.9 MHz as a paired spectrum for frequencies between 1475.9 MHz and 1510.9 MHz, and the use of the unpaired segment 1452 MHz – 1492 MHz as supplemental downlinks spectrum.[106] In all, 83 MHz of spectrum could be made available for mobile broadband service.

The band has so far been assigned to three primary uses: digital sound broadcasting (including satellite) though there is no use by this service; point-to-point and point-to-multipoint fixed links mainly in rural and remote areas;[107] and various uses by the Department of Defence. Therefore, these allocations will be directly affected, if and when the new arrangements are implemented.

A2-1.3.2 3.4GHz band

There are broadband wireless access licences in the 3.4 GHz band that will expire in December 2015. The ACMA expects to start discussions on technical framework in the third quarter of 2012. This will include consideration of new planning arrangements to provide greater spectrum and technology efficiencies. Reissue consideration is expected to commence in the second quarter of 2013.

New configurations for the band proposed by the 3GPP are a paired spectrum 3410MHz – 3500MHz/3510MHz – 3600MHz for use with LTE and LTE-Advanced in FDD mode and a 200MHz unpaired block between 3400MHz and 3600MHz for use in TDD mode.[108] Therefore, these are candidates for a new plan of the band, which will align Australia with international standards. Nevertheless, final decisions on re-planning will depend on the outcome of the consultation process with stakeholders.

106 http://www.acma.gov.au/WEB/STANDARD/pc=PC_410368.

107 The ACMA, however, also notes Telstra, the largest mobile operator, is the licensee for 83.5% of the licences, which may simplify re-purposing the band for mobile broadband.

108 http://www.acma.gov.au/webwr/_assets/main/lib312084/ifc13_2011_toward_2020-future_spectrum_requirements_errata.pdf.

A2-2 Europe

The information below on spectrum reviews and plans undertaken in Europe comes from published information and the results of our interviews with regulators in Europe.

In addition to the information reported below, we understand that there are some countries that have undertaken or are undertaking national inventories of spectrum use, but this information has not been published e.g. France and the UK.

A2-2.1 Denmark

The Danish Ministry of Commerce and Growth undertook a review of demand for spectrum and produced a draft spectrum strategy published on 26 October 2011.[109] This work identified the need for 300 MHz more spectrum for by 2020 and another 300 MHz by 2025 to support a 100 Mb/s broadband objective.[110] All bands between 400 and 4200 MHz were reviewed. The conclusions are given in Table 33. The potential for release of some of these bands will depend on European harmonisation initiatives.

Table 33: Candidate bands to meet future spectrum demand for wireless broadband services in Denmark

Frequency band	Bandwidth	Timescale	Candidate band?/Comments
470-790 MHz	320 MHz	2020	Possible candidate, but further evaluation and EU level decisions required. Band not available until 2020
1427-1452 MHz	25 MHz	2016	Yes/Need to consider existing users e.g. radio links, Defence
1452-1492 MHz	40 MHz	2014	Yes/Requires a change in media policy
1492-1518 MHz	36 MHz	2016	Yes/Need to consider existing users e.g. radio links, Defence
1525-1559 MHz and 1626.5-1660.5 MHz	68 MHz	Unknown	Not likely to be available for broadband services because of GMDSS
1785-1805 MHz	20 MHz	2014	Yes/depends on European strategy for PMSE use in the band
2300-2400 MHz	100 MHz	2015	Yes/Used for OB/ENG, audio links and wireless cameras, and fixed links
3800-4200 MHz	400 MHz	2020	Yes/relatively little use for fixed satellite communications

109 http://www.itst.dk/nyheder/nyhedsarkiv/2011/horing-over-udkast-til-frekvensstrategi.
110 The future need for broadband frequencies in Denmark, Analysys Mason, May 2011.

A2-2.2 France

The French government and regulators have undertaken national inventories of spectrum use in 2010 and 2011 with a view to identifying opportunities for spectrum supply to meet potential user demands. The inventory is to be updated annually and considered three distinct groupings of frequencies: below 223 GHz, 223 MHz-5 GHz and above 5 GHz. The results of the inventory are not published, but ANFr has reported that few bands are unused, and some are under study in CEPT and some are reserved for future use and a large part of the spectrum is already shared.[111]

In addition future spectrum requirements for a range of services have been assessed for the period up to 2020 for the Ministry of Economy. The estimates range from 570-670 MHz additional spectrum for a range of wireless communications services (government and commercial) and a possible reduction in requirements for TV broadcasting of up to 150 MHz. A plan for how these requirements might be fulfilled has not been published.[112]

However, ANFr published a review of fixed links bands in 2010.[113] The 1375-1400 and 1427-1452 MHz bands might be candidate bands as there are a limited number of microwave links using 25 KHz channels for PMR backhaul. There is a need to find a new band for existing links (limitation: radars in Spain). CEPT has started work on this band.

A2-2.3 Ireland

The Irish regulator Comreg produces a spectrum strategy statement every two years. The latest statement[114] foresees the potential spectrum release opportunities in the 400MHz -6GHz frequency range shown in the table below. We note these are additional to the ongoing process to auction 800 MHz, 900 MHz and 1800 MHz bands.

Table 34: Band planned for release in Ireland 2012-2014

Spectrum band	Timing/potential for release	Notes
1452-1492 MHz	Release subject to EU harmonisation measure being finalised	Significant interest in the band
1900-1905/1915-1920 MHz	Not under consideration	No interest
2010-2015 MHz	Potential to release	Limited interest
2300-2400 MHz	Consider once CEPT/EU harmonisation work is finalised	Considerable interest in this band
2500-2690 MHz	Limited options due to incumbents rights issues	Considerable interest in this band

111 See presentation: "Spectrum inventory Lessons learned and next steps", by D Chauveau, ANFr at http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/get_involved/activities/index_en.htm#past_workshops.
112 See, Assessment of Spectrum Needs in France by 2020, TERA, September 2011.
113 "Besoin en spectre du service de radiocommunication, ANFr, 2010".
114 Strategy for managing the radio spectrum 2011-2013, November 2011, Comreg 11/89.

A2-2.4 Netherlands

The Netherlands regulator, Agentschap Telecom (Ministry of Economic Affairs, Agriculture and Innovation), undertakes three regular activities aimed at understanding current spectrum use and to provide information for their future spectrum strategy. These activities are:

- An annual review of all spectrum use by non-public sector users which is published.[115]
- A review of trends in electronic communications and the implications for spectrum use and the regulator's work plan (the document is called ECD Radar 2012-206). The first review was undertaken in 2011 and looked out over the period 2012-2016. 30 action points were identified including actions around the possible need for more spectrum for mobile and licence exempt use.
- A three yearly review of spectrum use by government users which is not published. In this review, government users are required to justify their current and future spectrum requirements. The underlying philosophy is that these users should have sufficient spectrum to meet their needs but no more.

A2-2.5 Sweden

The Swedish regulator PTS produces a spectrum release plan on an annual basis – it is called a Spectrum Orientation plan.[116] The plan describes current and planned use of the radio frequency spectrum in Sweden.

In the 400- 6 GHz frequency range the following bands have been identified for further analysis and/or possible release:

- 3400-3600 MHz and 3800-4200 MHz are for further analysis.
- 450-470 MHz; 871-876 MHz; 916-921 MHz have been identified as possible WAPECs bands.
- The following bands have been identified as being available for possible award in 2012/2013 for WAPECs: 1452 - 1492 MHz; 2010 - 2025; 2300 - 2400.
- 1785 - 1805 MHz and 2700 - 2900 MHz have also been identified for possible award in 2012/2013 for WAPECS or PMSE applications.

In addition, S-band (2 GHz) is considered as vacant after the failure of Solaris Mobile in launching commercial services in the country and the absence of any plans from

115 The latest review can be found at http://www.agentschaptelecom.nl/binaries/content/assets/agentschaptelecom/Frequentiemanagement/staat-van-de-ether-2010.

116 http://www.pts.se/en-gb/Industry/Radio/Spectrum-Policy-and-Spectrum-Orientation-Plan/.

Inmarsat for launching commercial services despite having a licence. Some changes are also envisaged in C-band, 3.8 - 4.2 GHz and possibly 4.2 - 5.0 GHz in future.

PTS is also undertaking work to develop a spectrum strategy, and expects to publish the results from their inventory and demand analysis by early 2013.[117] The PTS spectrum strategy has the following elements:

- An inventory of spectrum use in 2012 based on numbers of assignments in each band.
- A forecast of potential spectrum demand in 2020.
- The development of principles and tools to be used to analyse the spectrum inventory data to arrive at an evidenced strategy that will optimise public welfare in light of future demands.
- Reviewing spectrum management tools and technical rules with a view to promoting more efficient spectrum use.

A2-2.6 UK

The UK regulator Ofcom does not have a process of regularly reviewing spectrum use. We understand from Ofcom that it is currently undertaking an inventory. One output from this work that has been published for consultation is a review of the use of fixed link bands.[118] In 2009, Ofcom published analysis of the demand for spectrum from a variety of applications and more recently has assessed ways of meeting demand for capacity from mobile broadband services.[119]

There has also been a programme of activity led by government to audit government spectrum use, with a view to improving efficiency taking account of current and future requirements.[120] As a result of this work, the UK government announced plans in October 2010 to release at least 500 MHz of government spectrum below 5 GHz over the coming ten years. This announcement was followed in March 2011 by a consultation document setting out some concrete proposals for bands that might be released.[121] When deciding which bands to release, the government proposed to look at bands that would meet expected demand, provide value, and are feasible to be released. Before making a decision on the release of any band, the government will need to carry out a cost-benefit analysis.

117 See presentation Spectrum Strategy Work in Sweden, Lena Liman, PTS, http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/get_involved/activities/index_en.htm#past_workshops.
118 http://stakeholders.ofcom.org.uk/consultations/spectrum-review/.
119 http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf; http://stakeholders.ofcom.org.uk/binaries/research/technology-research/shortage.pdf.
120 Martin Cave. December 2005. "Independent Audit of Spectrum Holdings." http://www.spectrumaudit.org.uk/pdf/20051118%20Final%20Formatted%20v9.pdf.
121 DCMS. 31 March 2011. "Enabling UK growth – Releasing public spectrum." http://www.dcms.gov.uk/images/publications/Spectrum_Release.pdf.

In December 2011, an update[122] on progress was published indicating the potential releases being examined and their timing. These are shown in Table 35. In addition to the bands shown in the table, the 4.2-4.2 GHz and 2.9-3.4 GHz bands may be examined in the longer term. Most of these bands are held by the Ministry of Defence.

Table 35: Bands allocated to government users that might be released in the future (UK)

Band	Potential release (MHz)	Timing	Possible uses
Currently prioritised for release			
2310-2390 MHz	40	160MHz by 2016 and remaining 40MHz by 2020	Public mobile
3400-3600 MHz	160		Public mobile
870-872 &915-917 MHz	4	By 2016	Smart grids
Sharing possibilities[123]			
870-872 &915-917 MHz , 1427-1452MHz, 2025-2070MHz, 4800-4900MHz	Up to 120 MHz	Under consideration	PMSE, machine to machine applications
Longer term releases to be investigated further			
2700-3100 MHz	Up to 100MHz	2016 onwards	Dependent on future studies
4400-5000	50MHz	2016 onwards	Dependent on future studies

A2-3 Japan

A2-3.1 Overview

The Ministry of Internal Affairs and Communications (MIC) acts as the regulatory body and spectrum management authority for Japan's telecommunications industry. It is wholly responsible for radio spectrum allocation to stakeholders in the market. The Radio Department, which sits in the Telecommunications Bureau of the MIC, regularly assesses the usage efficiency of assigned radio spectrum in order to determine whether frequencies are needed for their present purpose. The outcomes of the assessment are then used in the revision of policies on radio frequency assignment.[124]

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122 http://www.culture.gov.uk/images/publications/Spectrum-Public-Update-December-2011.pdf.
123 Details are given on the Ministry of Defence website http://www.mod.uk/DefenceInternet/AboutDefence/WhatWeDo/ScienceandTechnology/Spectrum/OtherSharingBands.htm.
124 http://www.deljpn.ec.europa.eu/data/current/2005-speech-19e-inada.pdf.

A2-3.2 Spectrum reviews

Since 2004, the usage situation for radio frequencies has been reviewed annually based on results obtained from the Radio Wave Usage Conditions Survey.[125] The number of active base stations for radio transmission over different frequencies, which are being used for their previously designated purposes, is taken to be a primary proxy for the utilisation rate of the spectrum in the survey. Where appropriate, the number of receiving units is used instead as a utilisation proxy. The MIC partitioned the entire spectrum into three categories for the purpose of the survey:

a) bands below 770 MHz

b) bands between 770 MHz and 3.4 GHz

c) bands above 3.4 GHz

Usage data is collected for each category on a 3-year rotation. The fiscal-year 2009 Radio Wave Usage Conditions Survey, published in 2010, looked at the frequency ranges above 3.4 GHz, and the survey for 2007 was conducted to examine usage of bandwidths above 770 MHz and below 3.4GHz. Meanwhile, the 2011 version of the survey focused on the use of frequency bands below 770MHz.

The MIC runs the survey at the end of a fiscal year and, shortly thereafter, publishes its findings as well as a draft of its own evaluations of the usage situation. Next, stakeholders are invited to comment on these results and draft evaluations. The MIC subsequently revises its Frequency Reorganisation Action Plan (a document detailing all changes to the existing bands) with substantial consideration given to conclusions drawn from the assessment of the survey results and the public consultation. This draft version of the action plan is released to the public for further comments. These comments are then used as input for the final version of the updated action plan. The first action plan was formulated in 2004, and it has since been revised according to the process described on roughly a yearly basis.

At present, the MIC continues to issue all new and relinquished blocks of spectrum through an administrative process. Proposals drafted in line with policies published in the action plan are submitted by stakeholders that are interested in the bands earmarked for allocation. They are then judged in a beauty contest, and licences are awarded to stakeholders with the best proposals that fulfil all technical and non-technical requirements specified by the MIC. The use of spectrum also carries an annual usage fee, which varies according to the type of radio base station used and proportionally with coverage area as well as the frequency range of the spectrum. In all cases, the fee reflects the administrative costs arising from spectrum allocation and reallocation. Such costs include the costs of central frequency database amendment and management and costs of policing frequency usage to ensure that illegitimate use

125 http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/NewsLetter/Vol20/vol20_24/vol20_24.html#p3.

is minimised. Expenses required to ensure usage compliance with imposed technical and non-technical licensing conditions and to promote efficient use of the spectrum are also taken into account in the calculation of the annual fee.[126] Fee revenues may, in some cases, be used to reimburse displaced incumbents for expenses associated with frequency migration.

A2-3.3 Spectrum reallocation plans

Spectrum reallocation is being used by the MIC to achieve the following purposes:

a) Attainment of a greater degree of contiguity of frequencies to enable a more efficient use of spectrum bands

b) Alignment of band usage with other countries to achieve greater harmonisation with other regions

c) Enhancement of speed on network operators' wireless broadband

d) Expansion of existing frequency bands to cope with rapidly increasing mobile data traffic volumes that result from surging demand for mobile broadband services and a rapidly growing diversity applications for mobile data communications

e) Creation of available frequencies in new bands that have been identified by international telecommunications associations as candidates for future generations of mobile technology.

Purposes b) to e) have been of particular interest to the MIC, and, in November 2010, it released an interim revision of the action plan. This version of the plan examines the policy implications of an accelerated reorganisation program for frequencies for mobile communications and other services in the 700 MHz and 900 MHz bands. In the February 2010 plan, the MIC proposed to release new spectrum bands for mobile communications – the targets were to release at least 300 MHz in the range 300-5000 MHz by 2015 and a cumulative total of at least 1,500 MHz by 2020.

Table 36 summarises the plans that Japan has for reassignment of spectrum to mobile communications services by 2015 in the 700-5000 MHz range. In total, 72MHz of additional spectrum in the 700MHz band will be available. In the 1.5GHz band, 19.3MHz of extra frequencies will be made available following the termination of land mobile service in the band in 2014. A further 200MHz bandwidth is also under consideration in the 3.4GHz band. This means that, by 2015, around 300MHz of additional spectrum will become available for mobile service compared to the level in 2010.

126 http://www.tele.soumu.go.jp/e/sys/fees/index.htm.

Table 36: Summary of allocations available for mobile communications services up to 2015[127]

Band	Present (May 2012)		End-2012		End-2015	
	Amount (MHz)	Range (MHz)	Amount (MHz)	Range (MHz)	Amount (MHz)	Range (MHz)
700 MHz	0	0	36	714-750	36	714-750
	0	0	36	770-806	36	770-806
800 MHz & 900 MHz	40	810-850	40	810-850	40	810-850
	43	860-903	55	860-915	55	860-915
	35	915-950	20	940-960	20	940-960
1.5 GHz	27.45	1427.9-1455.35	27.45	1427.9-1455.35	97.1	1427.9-1525
	38.35	1503.35-1465	38.35	1503.35-1465		
	12	1513-1525	12	1513-1525		
1.8 GHz	210	1710-1920	210	1710-1920	210	1710-1920
2 GHz	90	1920-2010	90	1920-2010	90	1920-2010
	15	2010-2025	15	2010-2025	15	2010-2025
	90	2110-2200	90	2110-2200	90	2110-2200
2.5 GHz	190	2500-2690	190	2500-2690	190	2500-2690
3.4 GHz					200	3400-3600
Total	**790.8**		**859.8**		**1079.1**	

A2-3.3.1 700 MHz

Following the completion of digital TV switchover in July 2011,[128] Japan has freed up frequencies in the range 710 MHz to 806 MHz. Field Pick-up Unit services for remote broadcasting transmission, which have been previously provided over the frequencies 770 MHz – 806 MHz, will be migrated to either the 1.2 GHz or 2.3 GHz band. Frequencies between 714 MHz and 750 MHz and in the range 770 MHz to 806 MHz will be repurposed for use with cellular phone service from 27 July 2012. The bandwidth 750 MHz – 770 MHz has been designated for use with ITS vehicle-to-vehicle and vehicle-to-road communication systems. These allocations are shown in Table 37.

127 These include frequencies assigned for use with mobile satellite services. Several bandwidths are not completely occupied, and these vacant IMT frequencies can be assigned in future to enable service expansion.

128 http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/110700_a.html.

Table 37: Frequency allocations in the 700MHz band from July 2012

Frequency range (MHz)	Use from July 2012
714-750 (UL), 770-806 (DL)	Cellular phone services
750-770	ITS vehicle-to-vehicle and vehicle-to-road communications system

The proposed allocation of the 700MHz band for mobile communications appears to be in accordance with Plan 3 of the four option plans that had been put forward by the MIC in 2010.[129] This plan will roughly align the frequencies with the APT 700MHz band plan for ITU Region 3.

A2-3.3.2 800 MHz and 900 MHz

The 810 MHz to 960 MHz band is being reorganised to give KDDI and NTT DoCoMo 2x15 MHz of contiguous frequencies and a potential 2x20 MHz in the GSM900 band (2x15 MHz has been assigned to Softbank) by July 2012. In total, there will be 2x40 MHz available for mobile communications in the 810 MHz - 850 MHz / 860 MHz - 895 MHz FDD band as shown in Table 38.

This reorganisation involves the cessation of personal radio service between 903MHz and 905 MHz and the proposed migration of land mobile service between 905MHz and 915 MHz to the range 930 MHz – 940 MHz in July 2012. The RFID service also migrates from 950 MHz – 958 MHz to 915 MHz – 930 MHz, freeing up 18 MHz between 940 MHz and 958 MHz. The 2 MHz chunk between 958 MHz and 960 MHz currently occupied by voice STL/TTL for broadcasting will be gradually moved.

Table 38: Frequency allocations in the 800 MHz and 900 MHz bands from July 2012 on

Frequency range (MHz)	Use from July 2012
810-815	Cellular phone services
815-845, 860-890	Cellular phone services (KDDI and NTT DoCoMo)
845-850	Cellular phone services
850-860, 930-940	MCA land mobile services
890-900	Cellular phone services
900-915, 945-960	Cellular phone services (Softbank)
915-930	RFID
940-945	Cellular phone services

129 http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/councilreport/pdf/101130_1.pdf.

A2-3.3.3 1.5 GHz band

Frequencies between 1427.9 MHz and 1525 MHz have been allocated for use in the provision of mobile communications services – namely uplink frequencies in the range 1427.9MHz - 1462.9MHz and downlink frequencies in the range 1475.9MHz – 1510.9MHz, with a guard band of 13 MHz between the uplink and downlink spectrum.[130] Operator-specific assignments can be found in Table 36.

Frequency licences for land mobile communications (MCA – Multi-Channel Access radio system), located in the ranges 1455.35 MHz – 1465 MHz and 1503.35 MHz – 1513 MHz will expire in 2014 as shown in Table 39. Once they expire, the full band will be made available for mobile communications services. This will enable the MIC to release 19.3 MHz of extra frequencies for mobile services.

Table 39: Frequency allocations in the 1.5GHz bands from July 2012

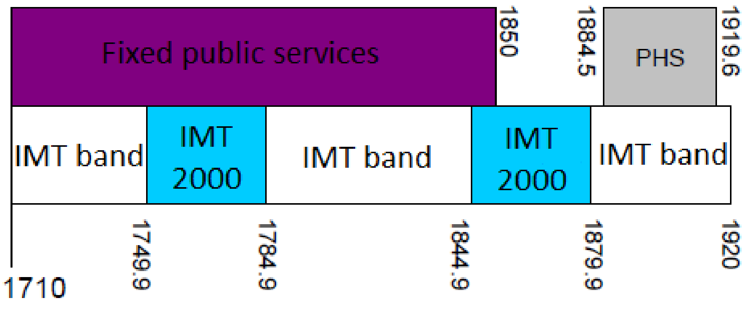
Frequency range (MHz)	Present use
1427.9-1455.35	Cellular phone services
1455.35-1465	Cellular phone services, MCA land mobile services
1465-1503.35	Cellular phone services
1503.35-1513	Cellular phone services, MCA land mobile services
1513-1525	Cellular phone services

A2-3.3.4 1.8 MHz band

There are two applications in this band: fixed public service (i.e. fixed government use) and mobile communications service. The current allocations are summarised in Figure 13. Here, IMT 2000 indicates chunks that have already been assigned for 3G mobile services. MIC plans to start assigning vacant spectrum in the blocks labelled IMT.

130 The MIC has assigned three adjacent blocks to Softbank, KDDI and NTT DoCoMo. Softbank and KDDI will have access to 2x10MHz, while NTT DoCoMo's licence is for a 15MHz pair.

Figure 13: Current allocations of the 1800MHz band in Japan



A2-3.3.5 2 GHz band

Frequencies in this paired spectrum band are currently being used for the provision of mobile 3G services through technologies that comply with IMT-2000 specifications. The 2 GHz frequency band has been assigned to the 3 operators as follows:[131]

a) NTT DoCoMo: 1940-1960/2130-2150 MHz

b) KDDI: 1925-1940/2115-2130 MHz

c) Softbank: 1960-1980/2150-2170 MHz

There is a spare 2x5 MHz block in the band.

The MIC has also released an unpaired block of 15 MHz between 2010 MHz and 2025 MHz for use with TDD mobile systems in July 2005[132]. The licence was eventually granted to a new start-up called IPMobile, which planned to use the frequencies for TD-CDMA and subsequently TD-SCDMA. However, the company went into administration in October 2007 before launching a service. The MIC still intends to assign the returned frequencies.

A2-3.3.6 2.5 GHz band

Frequencies in the range 2500 MHz – 2690 MHz are another IMT band in Japan. Those between 2535 MHz and 2630 MHz are currently allocated for use in the provision of broadband wireless access (BWA) service in TDD mode. Two operators have been awarded the permission to use these frequencies. UQ Communications, which offers mobile broadband service over WiMAX, has access to 30 MHz in the range 2595 MHz –

131 http://www.apt.int/sites/default/files/APT-AWF-REP-15_APT_Report_on_Mobile_Band_Usage.doc.
132 http://warp.ndl.go.jp/info:ndljp/pid/283520/www.soumu.go.jp/s-news/2005/pdf/050727_5_01.pdf.

2625 MHz, and WILLCOM's licence entitles it to the use of another 30 MHz-bandwidth between 2545 MHz and 2575 MHz.

At the moment, the empty block between 2630 MHz and 2655 MHz is under consideration to be issued as expansion band for BWA service. Meanwhile, frequencies between 2500 MHz and 2535 MHz and between 2655 MHz and 2690 MHz are used for mobile satellite. The present use of this band by frequency range is shown in Table 40.

Table 40: Current allocations of the 2.5GHz band in Japan

Frequency range (MHz)	Present use
2500-2535	Mobile satellite
2535-2630	Broadband wireless access service in TDD mode
2630-2655	Possible expansion band for broadband wireless access service
2655-2690	Mobile satellite

A2-3.3.7 3.4 GHz - 4.2 GHz band

Table 41 summarises the present usage scenario of this band for terrestrial transmission[133], [134] – these are secondary uses of the band for the auxiliary broadcast service.

Table 41: Present use of 3.4 - 4.2 GHz frequency band for terrestrial transmission

Frequency range (GHz)	Present use
3.4-3.4045, 3.4225-3.456	Studio-transmitter link (STL)/ transmitter-transmitter link (TTL)/ transmitter-studio link (TSL) for audio; broadcast telemetry information aggregation and dissemination
3.4045-3.4225	Field pick-up unit for audio broadcast from remote locations
3.456-3.6	Studio-transmitter link (STL)/ transmitter-transmitter link (TTL)/ transmitter-studio link (TSL) for video
3.6-4.2	Commercial fixed wireless telecommunications service including data communications

The MIC proposes to move entities that are currently using the frequencies for auxiliary broadcast services to a different band in order to free up 200 MHz of frequencies for use with IMT-Advanced mobile communication systems. For users of the 3.456-3.6 GHz band, the deadline for frequency migration is November 2012. In the reallocation action plan published in 2008, frequencies in the 6 GHz or above were tentatively

133 http://www.tele.soumu.go.jp/resource/search/myuse/use/10000m.pdf.
134 http://www.tele.soumu.go.jp/resource/e/search/myuse/use0303/10000m.pdf.

identified as possible candidate destinations for the transfer.[135] Transfer of the frequency range 3.4-3.456 GHz is expected to take place before 2015. Discussions are taking place on the details of the frequency arrangement, following the completion of the standardisation of 4G by 3GPP.

Users of the 3.6-4.2 GHz band for fixed wireless commercial telecommunications systems have been requested to either switch to using alternative frequencies in the 6 GHz band or to switch to an alternative technology such as optical fibre by November 2012.[136] There has been a significant decline in usage of this band for the designated purpose, which provides ground for the MIC's plan to free up the frequencies for use with future mobile service. According to the radio usage survey for fiscal year 2009, there were only 94 radio stations still in use in this frequency range for the purpose of providing fixed wireless communications. This number was 444 for fiscal year 2006.[137]

The use of the band for downlink transmission in fixed satellite communication system may be allowed to continue. In 2006, the MIC began conducting technical studies on shared utilization of the frequencies for 4G mobile communication systems and satellite communications in the frequency range. The MIC will use the final results of the investigation to formulate a concrete plan for spectrum sharing between mobile operators and satellite users. The process is scheduled to conclude in the first half of 2012.

A2-3.3.8 4.4GHz - 5GHz band

The MIC will also re-purpose frequencies in the range 4.4-4.9 GHz to achieve its goal of reallocating a total bandwidth of 1.3 GHz for use with 4G mobile communications system. At present, the frequency range 4.5-4.8 GHz is used for downlink transmission for fixed satellite communication as well as for high-capacity indoor data transmission. The band is used for the provision of commercial fixed wireless communications service on a secondary basis. The MIC has set a deadline of November 2012 for companies providing such services to migrate operation to a different set of frequencies. The MIC has yet to release the details of their reassignment plan for this band.

In total, the MIC proposes to requisition 1.1 GHz of additional frequency bandwidths in the 3-4 GHz range by 2020. The frequencies have been earmarked for use in enhancing the speed and capacity of cellular mobile communication systems.

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135 http://www.soumu.go.jp/menu_news/s-news/2008/pdf/081107_4_bs.pdf.
136 http://www.soumu.go.jp/main_content/000088588.pdf.
137 http://www.soumu.go.jp/main_content/000068134.pdf.

A2-4 United States

A2-4.1 Overview

Since the US National Broadband Plan was unveiled in 2010, there have been significant activities by the FCC and the NTIA towards the release/repurposing of spectrum for wireless broadband. The main developments so far are summarised as follows:

- 15 MHz (1695-1710 MHz) in the 1675-1710 MHz band to be made available within 5 years[138]
- 100 MHz (3550-3650 MHz) in the 3.5 GHz band to be made available with geographic limitations within 5 years[139]
- 25 MHz in the 2.3 GHz WCS band to be auctioned [140]
- 40 MHz (2000-2020/2180-2200 MHz) in the MSS S-band to be auctioned[141]
- 95 MHz (1755-1850 MHz) in the 1.7 GHz band to be made available within 10 years[142]
- 120 MHz (5350-5470 MHz) in the 5 GHz band to be made available for Wi-Fi[143]
- Licence conditions for SMR (813.5-824/858.5-869 MHz) relaxed to allow LTE deployment[144]
- FCC granted authority to conduct incentive auctions[145]

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138 NTIA Fast Track Evaluation, October 2010 http://www.ntia.doc.gov/report/2010/assessment-near-term-viability-accommodating-wireless-broadband-systems-1675-1710-mhz-17.
139 NTIA Fast Track Evaluation, October 2010.
140 http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-298308A1.pdf.
141 http://www.fcc.gov/document/fcc-proposes-40-mhz-additional-spectrum-mobile-broadband.
142 http://www.ntia.doc.gov/report/2012/assessment-viability-accommodating-wireless-broadband-1755-1850-mhz-band.
143 http://www.ntia.doc.gov/files/ntia/publications/second_interim_progress_report_on_the_ten_year_plan_and_timetable.pdf.
144 http://www.fcc.gov/document/800-mhz-smr-band-order.
145 http://www.fcc.gov/document/commissioner-clyburn-statement-voluntary-incentive-auctions.

Table 42: Key US spectrum developments as of May 2012

Band	Amount to be released (MHz)	Plans/ developments	Status/timescale
1695-1710 MHz	15	15 MHz to be made available with geographic limitations on wireless broadband implementation	By 2015
3.5 GHz	100	100 MHz (3550-3650 MHz) to be made available with geographic limitations on wireless broadband implementation Sharing between commercial and federal users Ideal for small cells	By 2015
1755-1850 MHz	95	Entire band to be made available by relocating existing federal users to other bands Some sharing likely to be required between commercial and federal users	By 2020
2 GHz (MSS S-band)	40	40 MHz (2000-2020/2180-2200 MHz) of Mobile Satellite Spectrum (MSS S-band) to be made available for terrestrial wireless broadband	Notice of proposed rule making (NRPM)
2.3 GHz	25	Revised technical rules to allow mobile broadband while protecting aeronautical mobile telemetry and satellite radio 25 MHz to be auctioned	Rules adopted No firm date for auction
5 GHz	120	5350-5470 MHz to be made available for unlicensed use/Wi-Fi NTIA and other federal agencies to evaluate spectrum sharing technologies and assess risk to existing federal users	No firm date
800 MHz	NA	Licence conditions for 800 MHz SMR (2G) services at 813.5-824/858.5-869 MHz to be relaxed to allow LTE deployment	Rules approved

A2-4.2 Key objectives

At present, the main activities around the release/repurposing of spectrum for mobile broadband being undertaken in the US are set out in two related initiatives namely:

- the National Broadband Plan[146] (administered by the Federal Communications Commission) to release 300 MHz by 2015
- the 500 MHz Initiative led by National Telecommunications and Information Administration (NTIA) to identify and release 500 MHz by 2020.[147]

In February 2012, the US Congress passed a key piece of legislation[148] which included a number of important spectrum related provisions as follows:

146 http://www.broadband.gov/.
147 http://www.ntia.doc.gov/category/500-mhz-initiative.

- FCC granted authority to conduct voluntary incentive auctions of underutilised spectrum made available by current holders for provision of new services.
- Allocation of 10 MHz of spectrum (700 MHz D-block at 758-763/788-793 MHz) for a nationwide, interoperable broadband network for public safety use.
- Clearing of federal spectrum between 1675 MHz and 1710 MHz – NTIA to submit a report identifying 15 MHz for reallocation from federal use to non-federal (commercial) use.
- Unlicensed use allowed in the 5 GHz band[149] and guard bands.

The following sub-sections present the plans and progress made so far in greater detail.

A2-4.3 US National Broadband Plan

The frequency bands under consideration in the US National Broadband Plan are:

Table 43: Specific targets in US National Broadband Plan

Band	Target	Progress (May 2012)
VHF and UHF TV bands (under 700 MHz)	To reallocate 120 MHz from broadcast TV bands	Feb 2012 – FCC granted authority to conduct incentive auctions
700 MHz D block (758-763/788-793 MHz)	To auction 700 MHz D block for commercial use that is technically compatible with public safety broadband services	Feb 2012 – D block allocated for public safety broadband network. Auction not yet scheduled
Mobile Satellite Spectrum bands (1525-1559, 1610-1626.5, 1626.5-1660.5, 2000-2020, 2180-2200, 2483.5-2500 MHz)	40 MHz from MSS L-Band	Feb 2012 – LightSquared's plans to provide satellite terrestrial service rejected due to interference with existing GPS services
	40 MHz from MSS S-Band	Mar 2012 – FCC to allow full terrestrial use by removing existing rules limiting band to satellite use (renamed AWS-4 band); FCC is consulting on band plan
	10 MHz from MSS Big LEO band	
AWS bands (1915-1920/1995-2000 MHz; 2020-2025/2175-2180 MHz; 2155-2175 MHz)	Up to 60 MHz from AWS bands to be auctioned (1915-1920/1995-2000, 2020-2025/2175-2180, 2155-2175) and 20 MHz from federal allocations at 1755-1850 MHz	Subject to finalisation of band plan for AWS-4
WCS band (2.3 GHz)	20 MHz to be made available while protecting neighbouring users	Revised rules on out-of-band emission limits have been adopted which enable mobile broadband use

148 Middle Class Tax Relief and Job Creation Act of 2012 http://docs.house.gov/billsthisweek/20120213/CRPT-112hrpt-HR3630.pdf.

149 5350–5470 MHz and 5850–5925 MHz.

A2-4.4 NTIA 500 MHz initiative

In parallel with FCC activities for the National Broadband Plan, the NTIA has been working with the Policy and Plans Steering group (PPSG) to identify candidate bands, set out a process to assessment and evaluation and identify necessary actions to meet the 500 MHz target. In October 2010, NTIA published its 10 Year Plan[150] which set out the process for achieving the 500 MHz target and the initial candidate bands. The FCC and the NTIA are undertaking spectrum inventory analyses focussing initially on bands in the 225 MHz to 4400MHz range.

The identification, prioritisation and subsequent evaluation of the candidate bands are based on a variety of factors, including:

- the amount of useable bandwidth to support wireless broadband and the degree to which that spectrum is contiguous;
- industry interest in the band and the expected auction revenue, if applicable, that the band will yield;
- indirect benefits to the economy of making the band available for wireless broadband;
- the availability of comparable spectrum (or other alternative arrangements) if relocation of incumbent users is necessary;
- the estimated costs of relocating Federal incumbents to another band;
- the impact to services using global allocations that would require international negotiations to bring about reallocation; and
- the likelihood that the band can be repurposed within ten years.

In undertaking this evaluation, the NTIA is to ensure that there is no loss of existing and planned Federal, State, local and tribal capabilities in connection with a reallocation.

The NTIA also published a fast-track evaluation of 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz and 4380-4400 MHz bands.[151] The report recommends that 115 MHz (1695-1710 MHz; 3550-3650 MHz) be made available for wireless broadband use in the next five years. NTIA has since submitted two interim reports on their progress in April 2011[152] and October 2011.[153] The NTIA has also published (in June 2010) a summary of Federal spectrum use.[154]

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150 http://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf.
151 http://www.ntia.doc.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf.
152 http://www.ntia.doc.gov/files/ntia/publications/first_interim_progress_report_04012011.pdf.
153 http://www.ntia.doc.gov/files/ntia/publications/second_interim_progress_report_on_the_ten_year_plan_and_timetable.pdf.
154 http://www.ntia.doc.gov/files/ntia/Spectrum_Use_Summary_Master-06212010.pdf.

A total of 13 bands are being considered as shown below – the 5350-5470 MHz band was added following industry interest in using the band for expanded Wi-Fi access and subsequently approved for unlicensed use by the US Congress in February 2012. These are shown in Table 44.

Table 44: Bands under investigation by NTIA

Band	Amount to be released (MHz)	Current use	Planned activity	Outcomes so far/comments
406.1-420 MHz	13.9	Federal: Fixed mobile, radio astronomy, space research. Non-federal: Radio astronomy	NTIA to study band for non-federal exclusive use	
1300-1390 MHz	90	Federal: Aeronautical radionavigation, radiolocation (exclusive federal use 1350-1390 MHz) Non-federal: Aeronautical radionavigation	NTIA to study 1300-1370 MHz for non-federal/federal sharing; 1370-1390 MHz for potential relocation	PPSG/NTIA may consider sharing entire 90 MHz for greater benefits
1675-1710 MHz*	35	Federal and non-federal: Meteorological Aids and Meteorological Satellite(1675-1700); Meteorological Aids and Fixed Services (1700-1710)	15 MHz (specifically 1695-1710 MHz) could be made available within 5 years for non-federal exclusive use	
1755-1850 MHz	95	Exclusive federal use	NTIA to study band for non-federal exclusive use	Assessment report concludes that entire band can be made available for mobile broadband but subject to relocation of federal users and some sharing
2200-2290 MHz	90	Federal: Space operation, earth exploration satellite, fixed mobile, space research	NTIA to study band for non-federal/federal sharing	
2700-2900 MHz	200	Federal: Meteorological aids, aeronautical radionavigation, radiolocation	NTIA to study band for non-federal/federal sharing	NTIA, PPSG may consider the feasibility of repacking radars so that they operate closer in order to open up portion of band for commercial use
2900-3100 MHz	200	Federal/non-federal: Radiolocation, maritime radionavigation	NTIA to study band for non-federal/federal sharing	
3100-3500 MHz	400	Federal: Radiolocation, earth exploration-satellite, space research Non-federal: Earth exploration-satellite, space research, radiolocation, amateur radiolocation	NTIA to study band for non-federal/federal sharing	

Band	Amount to be released (MHz)	Current use	Planned activity	Outcomes so far/comments
3500-3650 MHz	150	Federal: Radiolocation (Military radar), aeronautical radionavigation Non-federal: Radiolocation, fixed satellite	Fast track evaluation report recommends 3550-3650 MHz can be released for wireless broadband, with geographic limitations on implementation. Analysis so far suggests the need for large coastal exclusion zones[155]	The NTIA, FCC, federal agencies to determine feasibility of measures to allow industry to take responsibility for interference protection to increase coverage around coastal exclusion zones
4200-4400 MHz	200	Federal/non-federal: Aeronautical Radionavigation	Further review to confirm whether radio altimeters operate in these portions of the 4200-4400 MHz bands, and if so, are they impacted and to what extent (for non-federal exclusive use)	FAA conducting technical analysis
5350-5470 MHz	120	Federal and non-federal: Aeronautical Radionavigation; Earth Exploration-Satellite; Space Research; Radiolocation	NTIA, FCC, federal agencies, and industry to determine feasibility of expanding similar Wi-Fi operations into the 5350-5470 MHz band.	US Congress approved band for Wi Fi use NTIA, other agencies to evaluate spectrum sharing technologies and evaluate risk to existing federal users

The prioritisation of the bands for repurposing to wireless broadband use is shown in Table 45.

Table 45: Prioritisation of bands to be repurposed for mobile/wireless broadband

Licensed non-federal exclusive use bands	Non-federal/federal shared use bands
1. 1755-1850 MHz	1. 1300-1370 MHz
2. 1695-1710 MHz	2. 1675-1695 MHz
3. 406.1-420 MHz	3. 2700-2900 MHz
4. 1370-1390 MHz	4. 2900-3100 MHz
5. 4200-4400 MHz	5. 3100-3500 MHz
6. 3500-3650 MHz	6. 2200-2290 MHz

155 Under the NTIA proposal, non-Federal users would be prohibited from operating up to as much as 570 km from the U.S. coastline, and additional exclusion zones would be established for ten locations. NTIA also recommends that the FCC require the use of radio frequency front-end filters with between 30 and 40 decibels of attenuation at 3500 MHz in order to protect the new mobile and base station receivers from high power radar interference. The exclusion zones along the coasts were established due to potential interference from federal ship-borne radars to commercial mobile systems and are based on known protection levels of the broadband system receivers.

In March 2012, the NTIA published its assessment report on the 1755-1850 MHz band.[156] The key conclusion was that it is possible to reallocate all 95 MHz of the band, which is currently being used exclusively by federal agencies, for mobile broadband use.

The report also highlighted a number of challenges to be addressed in order to release the spectrum including: (a) finding spectrum with comparable capability to relocate existing federal users; (b) considering incumbent operations in selected relocation bands; (c) high costs and long timeline for relocation; and (d) convening stakeholder planning.

Relocation into the identified bands (e.g. 2025-2110 MHz) would need to take into consideration incumbent federal and/or non-federal uses in these bands which would require adequate protection from potential interference. NTIA notes that solutions such as spectrum sharing arrangements, partial clearing scenarios and a phased approach to commercial auctions and entry would need to be developed appropriately and these require cooperation and coordination between government and industry stakeholders. The costs of relocation are estimated at US$18 billion based on a phased relocation scenario over 10 years.[157]

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156 http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf.

157 As current US law requires auction proceeds to exceed expected federal relocation costs, any repurposing option needs to promote economic value while ensuring no loss of critical federal capabilities.

Annex 3: Correspondence between the application groupings for this prototype Spectrum Inventory and EFIS application categories

One of the objectives of the spectrum inventory process is to undertake analysis of spectrum efficiency across a wide frequency range (400 MHz to 6 GHz) and a large number of applications with very different technical and functional characteristics. To keep this efficiency analysis at a manageable level, it was decided to group together particular services or applications that share similar technical or functional characteristics and for which similar efficiency metrics might be applied. Since the existing EFIS data base is likely to form a principal input of source data for the inventory, consideration was also given to how such application groupings could be made compatible with the existing application definitions used in EFIS.

EFIS uses a three layer hierarchy of applications, as defined in ECC Decision (01)03. In some cases, the individual applications covered by an existing Level 1 definition are sufficiency similar for the same Level 1 definition to be used as one of the groupings for the inventory analysis. However, in other cases the Level 1 definitions were found to be either too broad in scope to apply a single set of efficiency metrics. For example, the level 1 application “Land Mobile” does not differentiate between cellular services and private mobile radio, which tend to use spectrum in a very different way and are generally subject to quite different licensing processes. In other cases, such as aeronautical and maritime, it was considered that similar metrics could be applied to multiple Level 1 categories.

We therefore decided to adopt an approach based on fourteen application groupings, some of which correspond to existing EFIS level 1 or 2 applications, whilst others cover several applications on the basis that these have similar technical and functional characteristics. To facilitate exchange of date between EFIS and the inventory, each EFIS Layer 2 application has been associated with a specific application category for the purposes of efficiency analysis within the inventory.

The fourteen proposed application groupings are:

1. Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)
2. Broadcasting (Terrestrial)
3. BWA / Cellular
4. Defence Systems
5. Fixed Links
6. Intelligent Transport Systems (ITS)
7. Meteorology

8. PMR / PAMR
9. PMSE
10. PPDR
11. Radio Astronomy
12. Satellite Systems (Civil)
13. Short Range Devices (SRDs)
14. Wideband data transmission systems

The tables overleaf summarise the mapping between the current EFIS definitions and the application categories that are planned to be used in the inventory for efficiency analysis purposes and provides an explanation where there is a difference between the terms used.

Table 46: Mapping of EFIS Applications to Inventory Application Groupings

EFIS Layer 1	EFIS Layer 2	Application Grouping for Inventory efficiency analysis	Comments
Aeronautical	Aeronautical communications	Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)	Similar communication, radiolocation and radionavigation requirements apply across aeronautical and maritime sector.
	Aeronautical navigation		
	Aeronautical surveillance		
	Aeronautical emergency		
	Aeronautical telemetry		
	Aeronautical telecommand		
	Aeronautical telemetry/telecommand		
	Satellite navigation systems		
Broadcasting	Broadcasting (terrestrial)	Broadcasting (terrestrial)	
	Broadcasting-satellite receivers	Satellite systems (civil)	Propose to group together with other satellite services for efficiency analysis
	SAP/SAB and ENG/OB	PMSE	Reflects current terminology
Fixed	Point-to-Multipoint	Fixed Links	
	Point-to-Point		
	BWA	BWA / Cellular	Reflects trend towards service neutrality
	MFCN		
Defence systems	Aeronautical military systems	Defence Systems	
	Land military systems		
	Maritime military systems		
	Meteorological aids (military)		
	Radiolocation (military)		

EFIS Layer 1	EFIS Layer 2	Application Grouping for Inventory efficiency analysis	Comments
	Satellite systems (military)		
	Telemetry (military)		
	Telecommand (military)		
	Telemetry/Telecommand (military)		
Land mobile	Digital cellular	BWA / Cellular	Reflects trend towards service neutrality
	BWA		
	ITS	ITS	New transport related services may require specific efficiency criteria
	Analogue cellular	BWA / Cellular	
	Cordless telephones	SRDs	Reflects licence exempt status
	D-GPS	Not currently included	Not under consideration currently
	Emergency services	PPDR	Reflects current terminology
	Inland waterway communications	PMR/PAMR	Reflects commonalities between these services (e.g. technology, functionality)
	MFCN	BWA / Cellular	
	Paging	PMR/PAMR	Reflects similarity between these services
	PMR/PAMR		
	SAP/SAB and ENG/OB	PMSE	Reflects current terminology
	Telemetry (civil)	Fixed Links (licensed) or SRDs (licence exempt)	These are generally fixed (point to multipoint) systems rather than mobile (though often deployed in mobile bands)
	Telecommand (civil)		
	Telemetry/Telecommand (civil)		

EFIS Layer 1	EFIS Layer 2	Application Grouping for Inventory efficiency analysis	Comments
Maritime	GMDSS	Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)	Similar communication, radiolocation and radionavigation requirements apply across aeronautical and maritime sector.
	Satellite navigation systems		
	Maritime communications		
	Maritime navigation		
Meteorology	Oceanographic buoys	Meteorology	
	Sondes		
	Weather radar		
	Weather satellites		
	Wind profilers		
Satellite systems (civil)	Aeronautical satcoms	Satellite systems (civil)	
	Amateur-satellite		
	Broadcasting-satellite receivers		
	Earth exploration-satellite		
	Feeder links		
	FSS Earth stations		
	Inter-satellite links		
	MSS Earth stations		
	Satellite navigation systems	Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)	Reflects functional similarity to other navigation systems
	Standard frequency and time signal-satellite	Satellite systems (civil)	
	Space operations		
	Space research		

EFIS Layer 1	EFIS Layer 2	Application Grouping for Inventory efficiency analysis	Comments
Radio astronomy	Continuum measurements	Radio Astronomy	
	Spectral line observations		
	VLBI observations		
Short Range Devices	Alarms	Short Range Devices (SRDs)	
	Railway applications	Intelligent Transport Systems (ITS)	New transport related services may require specific efficiency criteria
	Tracking, tracing and data acquisition	Short Range Devices (SRDs)	
	Radiodetermination applications		
	Inductive applications		
	Active medical implants		
	Model control		
	Non-specific SRDs		
	Radio microphones and ALD		
	Wideband data transmission systems	Wideband Data Transmission	Likely to require different efficiency criteria from other SRD applications
	RFID	Short Range Devices (SRDs)	
	RTTT	Intelligent Transport Systems (ITS)	New transport related services may require specific efficiency criteria
	UWB applications	Short Range Devices (SRDs)	
	Wireless audio applications		
TRA-ECS		BWA / Cellular	

EFIS Layer 1	EFIS Layer 2	Application Grouping for Inventory efficiency analysis	Comments
Other	Amateur	Not currently included	
	CB radio		
	GNSS Repeater		
	HAPS		
	ISM		
	Meteor scatter communications		
	Land radionavigation	Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)	
	Radiolocation (civil)		
	Standard frequency and time signal	Not currently included	
	Tracking systems		

Table 47: Mapping of Inventory Application Groupings to EFIS Applications (Level 2)

Application Grouping for efficiency analysis	EFIS Layer 2 Applications
Aeronautical, Maritime and Civil Radiolocation / Navigation Systems (AMCRN)	Aeronautical communications
	Aeronautical emergency
	Aeronautical navigation
	Aeronautical surveillance
	Aeronautical telecommand
	Aeronautical telemetry
	Aeronautical telemetry/telecommand
	GMDSS
	Land radionavigation
	Maritime communications
	Maritime navigation
	Radiolocation (civil)
	Satellite navigation systems
Broadcasting (Terrestrial)	Broadcasting (Terrestrial)
BWA / Cellular	Analogue cellular
	BWA
	Digital cellular
	MFCN
	TRA-ECS (Level 1)
Defence Systems	Aeronautical military systems
	Land military systems
	Maritime military systems
	Meteorological aids (military)
	Radiolocation (military)
	Satellite systems (military)
	Telemetry (military)
	Telecommand (military)
	Telemetry/Telecommand (military)
Fixed Links	Point-to-Multipoint
	Point-to-Point
	Telemetry (civil)
	Telecommand (civil)
	Telemetry/Telecommand (civil)
Intelligent Transport Systems (ITS)	ITS
	Railway Applications
	RTTT

Meteorology	Oceanographic buoys
	Sondes
	Weather radar
	Weather satellites
	Wind profilers
PMR / PAMR	Inland waterway communications
	Paging
	PMR / PAMR
PMSE	SAP/SAB and ENG/OB
	Radio Microphones
PPDR	Emergency Services
Radio Astronomy	Continuum measurements
	Spectral line observations
	VLBI observations
Satellite Systems (Civil)	Aeronautical satcoms
	Amateur-satellite
	Broadcasting-satellite receivers
	Earth exploration-satellite
	Feeder links
	FSS Earth stations
	Inter-satellite links
	MSS Earth stations
	Satellite navigation systems
	Standard frequency and time signal-satellite
	Space operations
	Space research
Short Range Devices (SRDs)	Active medical implants
	Alarms
	Inductive applications
	Model control
	Non-specific SRDs
	Radio microphones and ALD
	Radiodetermination applications
	RFID
	Tracking, tracing and data acquisition
	UWB applications
	Wireless audio applications
Wideband data transmission systems	Wideband data transmission systems