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Comparison of selected natural capital accounting frameworks

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Disclaimer

List of Abbreviations

AEEA – Australian Environmental-Economic Accounting, by Australian Bureau of Statistics (ABS)
ANS – Adjusted Net Savings, World Bank
CWI – Comprehensive Wealth Index, developed by the World Bank
GDP – Gross Domestic Product
GPI – Genuine Progress Indicator, developed by Cobb, Halstead and Rowe (Cobb et al., 1995)
GNI – Genuine National Income
IWI – Inclusive Wealth Index, developed by UNU-IHDP
NAS – Adjusted Net Savings Rate (ANS/GNI)
NPV – Net Present Value
NNP - Net National Product
NTFP – Non-timber Forest Products
PES – Payments for Ecosystem Services
SEEA – System of Environmental-Economic Accounting, hosted by UNSC and others
SEEA-CF – SEEA – Central Framework
SEEA-EEA – SEEA **-** Environmental Ecosystem Accounting
TEEB – The Economics of Ecosystems and Biodiversity, hosted by UNEP
TEV – Total Economic Value
THR – Total Hotelling Rent
UK-NEA – National Ecosystem Assessment, UK, Office for National Statistics
UNEP – United Nations Environment Programme
UNSC - United Nations Statistical Commission
UNU-IHDP – United Nations University – International Human Dimension Programme
VES – Value of Ecosystem Services

Chapter 1 Introduction

It is nowadays commonly recognized that the world economies are highly dependent on the environment. This is the case not only regarding the direct products that can be derived from natural resources, but concerns also the indispensability of other types of ecosystem services. For instance, nature's capacity to act as a sink for the waste and emissions resulting from human activities is essential to the world economies. As this fundamental link between nature and the economy became more apparent, the need for a change in the measurement approaches of world economies proved to be vital. As a result, great efforts are nowadays being made for the transition to a 'Green Economy' (UNEP, 2011). This implies protecting the natural resources, and employing strategic policies that ensure environmental sustainability while stimulating economic growth – 'Green Growth' (The World Bank, 2012a). Nonetheless, despite the past decades efforts to facilitate the transition to a sustainable world, rapid population growth, dwindling natural resources, as well as the changes generated in the Earth processes (e.g. increased eutrophication worldwide, depletion of the ozone layer), are pushing humanity to the limit, imposing an ever higher need for greening the global economy (Planet Under Pressure, 2012).

Ever since its creation, the Gross Domestic Product (GDP) has often been used to quantify a variable that it was never designed for – economic and human well-being (Costanza et al., 2009). This misuse has been continuing for decades, despite the required caution emphasized upon by its creator in 1934, Simon Kuznets (Kuznets, 1934). GDP only measures the monetary value arising from trade of produced goods and services within a contained space and period of time. It does not account for externalities that emerge from this production, such as the impact on social well-being, or the damage imposed upon the natural environment. Therefore, it can lead to misleading results, such as portraying the impacts of natural disasters (e.g. Hurricane Sandy in 2012) as positive for the economy, since reconstruction increases production (Costanza et al., 2014).

Numerous indices of sustainability have been developed in the past decades, analysing the social, economic, and environmental impacts of human activities. However, in order to fully integrate these three aspects, a common valuation ground needs to be employed. Such integration was done by the wealth accounts, by setting a monetary value on the social and natural resources of a country.

Problem Definition

Countries are beginning to use natural capital accounting frameworks in order to keep track of their natural assets. Nonetheless, there is great concern regarding the capability of these frameworks to fully and accurately encompass the value of natural resources. Substantial shortcomings are still present in their methods of valuing natural capital, such as omitting important ecosystem services (e.g. regulating services) and externalities that spring from the exploitation of the natural resources. The question remains of how large the contribution of these services and externalities is, as well as how to integrate them in the existing frameworks.

As different wealth accounting frameworks are based on distinct valuation approaches of natural resources, potential users need a deeper insight into their advantages and disadvantages. Such an understanding would allow employing the framework that best suits the given needs. Furthermore, end users of wealth accounting frameworks would also need to know what the main assumptions and limitations in the methodologies are. Such knowledge can shine light on the potential risks of relying on a specific framework.

Research Purpose

This study assesses the discussed gaps in the nature valuation methodologies employed by three selected wealth accounting frameworks, and provides an analysis of the advantages and disadvantages of their methodologies. The wealth accounting frameworks that will be discussed in this study are: the Comprehensive Wealth Index (CWI), developed by the World Bank (Hamilton, 2006), the Inclusive Wealth Index (IWI), created by UNU-IHDP and UNEP (UNU-IHDP and UNEP, 2012), and the System of Environmental-Economic Accounting (United Nations et al., 2012a). Given that only the natural capital accounting aspect of these systems will be considered in this study, the wealth accounting frameworks approaches to value natural capital will be referred to as 'natural capital accounting frameworks'.

Objective

The main objective of this thesis is to compare, and where possible, assess the advantages and the disadvantages of selected existing natural capital accounting frameworks (IWI, CWI, SEEA) in terms of their approaches in providing a monetary value for the natural capital of countries. In order to conduct this assessment, other natural capital indicators will also be compared to identify potential valuable additions to the natural capital accounting frameworks (inclusion of non-marketed ecosystem services and considerations of externalities). These additional natural capital indicators are the Adjusted Net Savings (ANS), the Genuine Progress Indicator (GPI), and The Economics of Ecosystems and Biodiversity (TEEB).

Research Questions

1. What are the differences in valuation approaches of selected natural capital accounting frameworks (IWI, CWI, SEEA)?
2. Would the inclusion of non-marketed ecosystem services, as valued across studies available in TEEB database, lead to significant changes in the total natural capital value determined by the natural capital accounting frameworks (IWI, CWI, SEEA)?
3. Are there numerical or methodological correlations between natural capital accounting value changes and environmental costs (lost natural capital and externalities) determined over a given period of time by ANS and GPI?

Thesis structure

The current thesis spreads over eight chapters. After a brief introduction to the subject and the purpose of the research (Chapter 1), more details on the topic background are provided in Chapter 2 (Theoretical Framework). Before delving into answering the research questions, a thorough description of the methodology used in this study is elaborated in Chapter 3. Chapters 4, 5, and 6 provide the results of applying the methodology to answer the research questions. The discussion on these findings is provided in Chapter 7, followed by Conclusions in Chapter 8.

Chapter 2 Theoretical Framework

2.1 Introduction

The importance of considering wealth accounting as distinct from the income accounting, in the assessment of intergenerational well-being was revealed long before the Brundtland Report (WCED, 1987) was published. Nonetheless, once the issue of sustainability surfaced with this report, significant progress was made in the area of wealth, welfare, and the inclusion of environmental assets in systems of national accounts. From a social welfare theoretic standpoint, sustainability can be interpreted as a non-declining utility for all future generations (Pezzey, 1990). Assuming that utility depends only on consumption, then non-declining utility would imply non-declining consumption. Solow (1993) argued that an appropriate approach in measuring national accounting would have the capacity to promote and ensure sustainability. He also suggested the use of a well-defined net national product (NNP) to measure the maximum sustainable user satisfaction level, which can also be seen as society's interest on the total capital stock (reproducible and resource stock). In order to maintain the capital stock intact and to follow a sustainable path, only the interest can be consumed. Furthermore, Hartwick's rule for sustainable development demands the investment of resource stock depreciation into reproducible capital (Hartwick, 1977). The World Bank (2011) showed that by not following Hartwick's simple rule of sustainability, many countries recorded significant wealth losses.

Substantial work has been done to adjust the national accounts in order to account for resource depreciation and to build the wealth accounts (Hartwick, 1990; Hung, 1993; Davis & Moore, 2000). One approach in measuring depreciation of a non-renewable resource as a result of extraction is the total Hotelling rent (THR), as described by the equation below.

$$THR_t = (P_t - c_t)(R_t - N_t) \tag{2.1}$$

where *t* indicates discrete time P_t is the market price of the resources, c_t is the marginal cost of extraction, R_t is the amount extracted, and N_t stands for the resource additions due to new discoveries. If the stock is fixed (no new discoveries), this approach assumes an optimal extraction path which would lead to a price increase with the rate of discount (Davis & Moore, 2000; Perman et al., 2011). In a perfectly competitive economy, THR_t would be equal to the change in market value of the non-renewable resource at stake. However, a series of shortcomings limit the potential of this simple theoretical measure in practice. Firstly, the marginal cost, c_t, cannot be easily derived from any available data. Secondly, the economy can rarely be characterized as competitive, and even less so in the case of mineral resources.

2.2 Natural capital depreciation

On the practical side of environmental accounting, only three methods appear to be prevalent: net price, change in net present value, and El Serafy's (user cost) rule. These three methods will be presented in more detail below.

Net price

In order to tackle the issue of unavailable marginal costs, this method employs average costs instead, *C*. Hence, depreciation, D_t, becomes

$$D_t = (P_t - C_t)(R_t - N_t) \tag{2.2}$$

The first issue that arises with the use of this method is that, if $c_t > C_t$, than D_t would be overestimated, while if $c_t < C_t$, which is less likely to occur, D_t would be underestimated. The other shortcoming springs from the fact that valuation is in this case performed over a longer period of time (to average over costs), instead of an instant in time. This change also imposes a different approach on the use of P_t and N_t. The price is most likely to vary over time, while the value of N_t depends on the start and end period considered. Whether the value of N_t will be fixed at the end or the beginning of the period, or whether it would be taken as an average, would give different result. In some cases, this method ignores new discoveries, becoming less affected by required assumptions, and providing less volatile estimates. However, it also leads to higher estimates than when N_t is accounted for. Furthermore, ignoring N_t would always give a larger value than the El Serafy's rule, described below.

This method is likely to produce highly volatile depreciation estimates from one year to another. However, the advantages brought by this method spring from the fact that it does not require information or assumptions about resource stock lifetimes and interest rates, like the other methods do.

Expanding from this method, Miller & Upton (1985a) showed that the value of a resource stock could be determined as the product between the current price and the total stock. However, the valuation method has been shown to produce high inaccuracies in practice, undervaluing or overvaluing the reserves (Davis & Moore, 2000). By allowing for non-constant returns to scale and cumulative production, Davis & Moore (2000), produced a more general valuation method that may improve the results. Nonetheless, a lack of appropriate data make this method difficult to use.

Change in net present value

For a period indicated as starting at *0* and ending at *1*, the change in net present value would be represented by the following formula

$$D = \sum_{t=0}^{T_0} \frac{(P_t - C_t)R_t}{(1+i)^t} - \sum_{t=1}^{T_1} \frac{(P_t - C_t)R_t}{(1+i)^t} \tag{2.3}$$

where i is the interest rate, while T_0 and T_1 are the deposits lifetimes at time 0 and 1. It is important to note, that in this case as well, c is replaced by C, while N disappears completely. This method has the advantage of providing less volatile results, due to the exclusion of the new discoveries. New discoveries would have an impact on the lifetime of the resource, T_1. However, the depreciation in this method is built in such a way that the value of future flows is extracted from one another, focusing only on the future. Furthermore, in what concerns the net present value of a non-renewable asset, if the lifetime of the resource was already sufficiently long, prolonging it would not have a high impact, as extraction in the far future is highly discounted.

The use of this method in valuing natural capital assets is seen by Davis & Moore (2000) as an ad-hoc approach that does not imply any optimization assumptions. The same authors also claim that, although THR was shown to be an inappropriate method, some accountants find the net present value approach to be even more problematic for not possessing a comprehensive optimisation framework. Assumptions regarding prices, costs, and extraction paths at T_1, as well as the lifetime value itself, would have a high impact on the final depreciation value.

El Serafy's (user cost) rule

El Serafy (1989) proposed this method as an approach to measure depreciation as 'user cost'. User cost is defined as the difference between the net receipts and the constant income stream (current value of the resource deposit).

$$D_t = \frac{R_t(P_t - C_t)}{(1+i)^T} \tag{2.4}$$

where T is the lifetime of the deposit, assuming constant extraction rate. This approach suggests that any current exploitation of a resource should be seen as a reduction of the future inflows at the very end of a resource lifetime (or a shortening of the resource lifetime). However, in its current form, this method assumes constant costs and prices between the current period and time T, an assumption that is highly unlikely to hold. Hence, criticism concerning optimisation applies to this method as well as to the NPV method.

Comparing the depreciation approaches

Perman et al. (2011) demonstrates that these three methods provide very different results when applied to the same data. From a capital-theoretic standpoint, the Net price (including new discoveries) would be the most appropriate measure, as it resembles THR the most. However, the fact that the average value of costs is likely to be lower than the marginal value implies that the estimates generated by means of this method should be treated as an upper limit. On the other hand, the depreciation approach based on Hotelling rent was greatly criticized later on, because considering all revenues a social cost would be equivalent to assuming that a non-renewable resource does not bring value to society (Cairns, 2004). Cairns (2004) suggests that the depreciation of non-renewable resources is lower than assumed in previous methods using Hotelling rule.

Perman et al. (2011) also showed that the inclusion of new discoveries in the first two methods presented can lead to negative depreciation values (when the new discoveries are substantial), and to high estimates volatility from one year to another.

The methods described in the previous section have been designed specifically for non-renewable resources. However, the same methods could be applied to renewable resources, where the place of new discoveries could be taken by the natural growth of the natural capital asset.

2.3 Wealth and natural capital accounts

Wealth accounting was developed with the aim of creating indicators of human welfare and sustainability. If it is accurately determined, this indicator has the potential to become a measure of 'weak sustainability', under the assumption that the different types of capital can substitute each other as long as the value is similar (Pearce & Atkinson, 1993). Hence, any decrease in the total wealth value can be seen as a sign of unsustainability (Obst & Vardon, 2014). Similarly, a positive depreciation of any asset would be a sign of unsustainability under a 'strong sustainability' context, which implies non-substitution between different assets (ibid.). According to El Serafy (1997), national accounts favouring strong sustainability should focus on stocks, as no asset substitution is allowed, while national accounts concerned with weak sustainability would benefit more from employing a flows approach, assuming that substitution is possible. However, the manner in which national capital accounting systems are currently formulated makes the wealth indicator be concerned with production sustainability only, and not welfare sustainability, as only market values are recorded (Lintott, 1996).

National accounting systems generally represent a set of assets possessed by a country, and the changes of these assets in physical and monetary terms. Natural capital is part of these assets, and therefore, these accounting systems contain data on stocks, flows and monetary values of natural resources. Natural capital assets can include forests, cropland, fisheries, mineral resources, and any other natural resources that provide goods and services for human use.

Three main natural capital accounting frameworks take different approaches to determine a monetary value of natural capital at a national level – the Comprehensive Wealth Index (CWI), developed by the World Bank (Hamilton et al., 2006), the Inclusive Wealth Index (IWI), created by UNU-IHDP and UNEP (UNU-IHDP and UNEP, 2012), and the System of Environmental-Economic Accounting Central Framework as a satellite of the System of National Accounts (United Nations et al., 2012a). Nonetheless, substantial shortcomings still remain in these natural capital accounting methods, and one of them is the need to include the value of non-marketed ecosystem services.

2.4 Ecosystem services valuation

Although significant progress has been made in the area of ecosystem valuation, experience with integrating ecosystem services and ecosystem capital value in the national accounts is still limited (Edens & Hein, 2013). Given that wealth accounts aim to be based on the theory of welfare, the value of natural capital must be determined from a welfare-theoretic standpoint. Natural resources encompass various ecosystem services that create utility and whose values need to be added up in order to obtain a total welfare value. In theory, the value of ecosystem services (VES) can be determined by multiplying the quantity of natural capital by the corresponding shadow price (Howarth & Farber, 2002; Obst & Vardon, 2014). Shadow prices are defined as the social worth of a marginal unit of an asset (change in wealth per change in capital stocks). Nonetheless, in practice, estimation of shadow prices is nontrivial and a replacement with market prices often leads to an underestimation of the natural resource value, as non-marketed services would in most cases not be accounted for (Hueting & Leipert, 1990, El Serafy, 1997). Additionally, the issue of double counting should be treated with due diligence as market prices sometimes incorporate the value of non-marketed services (e.g. the value of bee pollination is reflected in the crop production).

Edens & Hein (2013) define ecosystem services, from an ecosystem accounting perspective, in terms of their input to productive activities (provisioning services, such as timber) and consumptive activities (e.g. recreational value of nature). In this work, ecosystem services are categorized as provisioning, regulating and cultural services. Provisioning services represent a physical flow from a natural resource, a direct input into productive human activities. Regulating services do not represent physical flows of a resource, but rather a flow of benefits that spring from the existence of a resource (e.g. pollination). Cultural services relate to the value that people obtain from visiting natural sites, or by simply knowing that they exist.

When the value of ecosystems is not fully represented by the market price (additional non-market services), it can be determined by other methods. The six major methods for valuing non-marketed ecosystem services are the following (as presented by Farber et al., 2002):

- avoided cost (cost in the absence of ecosystem services, e.g. flood control cost);
- replacement cost (cost of man-made technologies to replace ecosystems, e.g. waste treatment);
- factor income (services that lead to higher income, e.g. improved water quality in fishing);
- travel cost (money spent to travel to a natural area for recreation)

- hedonic pricing (people would pay higher prices for goods that come with extra services, e.g. housing close to a natural area)
- contingent valuation (willingness to pay for hypothetical scenarios, e.g. increased fish catch)

While some authors (Sagoff, 1988) suggest that ecosystem services relate to social value that cannot and should not be monetized, sustainably managing natural resources highly depends on our understanding of the value they bear (Howarth & Farber, 2002; Lintott, 1996). For this reason, national accounts that aim to act as sustainability indicators should be able to encompass the value of all benefits that a country draws from natural resources.

2.5 Adjusted Net Savings and Genuine Progress Indicator

In the previous sections it was suggested that the changes in wealth could be seen as indicators for sustainability levels. However, Hamilton and Clemens (1999) claim that adjusted net (genuine) saving can be seen as the monetary value of a change in social wealth. Furthermore, it is also a direct indicator of sustainability. If the adjusted net saving is negative or positive it is implied that the future utility will be less or more, respectively, than the current utility over a certain period of time.

The adjusted net savings framework is based on the assumption that a nation's productivity depends on human and natural capital. Therefore, depletion of natural resources is perceived as a disinvestments, while an improvement in education is seen as an investment in the future productivity and well-being of the population. Produced capital is liable to depreciation, while pollution represents a negative impact on the environment (Bolt et al. 2002). Taking all these terms into account, the adjusted net savings rate (adjusted net savings as a factor of gross national income) was formulated by Bolt et al. (2002) as follows:

$$NAS=(GNS-D_h+CSE-R_{n,i}-CD)/GNI \quad (2.5)$$

where NAS = Adjusted Net Savings Rate, GNS = Gross National Saving, D_h = Depreciation of produced capital, CSE = Current (non-fixed-capital) expenditure on education, $R_{n,i}$ = Rent from depletion of natural capital, CD = Damages from carbon dioxide emissions, GNI = Gross National Income at Market Prices. The indicator used in this study is the Adjusted Net Savings (ANS):

$$ANS=GNS-D_h+CSE-R_{n,i}-CD \quad (2.6)$$

The Genuine Progress Indicator (GPI) is an indicator that aims to measure the impact of a growing economy, the costs and benefits at a social and environmental level. GPI was constructed in a response to the deficiencies posed by the GDP indicator in measuring true welfare development. However, GPI simply measures the cumulated cost and benefits of a set of social, economic, and environmental items, but it cannot directly indicate whether sustainability is achieved or not. Furthermore, the list of items considered by GPI is not exhaustive and this might hide very important (dominant) impacts of economic activity.

From an environmental perspective, GPI includes estimates of costs attributed to loss of natural capital services (e.g. loss of agricultural land, timber depletion), as well as the impact of pollution (e.g. air pollution) (Lawn, 2003; Lawn & Clarke, 2008). The list of items considered in the calculations and the methodologies used vary significantly between different studies.

Chapter 3. Methodology

3.1 Research Questions Appr

Throughout the thesis, data is presented in USD (US dollar) of the year 2000. In order to address inflation and deflation, the US inflation calculator was used (http://www.usinflationcalculator.com/). Furthermore, it was also necessary to change values from one currency to another. In order to change from GBP (Great Britain Pounds), ZAR (South African Rand), and from AUD (Australian Dollar) to USD, spot exchange values provided by the Bank of England (http://www.bankofengland.co.uk) were used. On the other hand, CNY (Chinese Yuan), JPY (Japanese Yen) and INR (Indian Rupee) were changed to USD using Oanda online currency exchange (http://www.oanda.com/currency/average).

In this study, data for IWI has been extracted from UNU-IHDP & UNEP (2012), while CWI estimates were obtained from the World Bank database accompanying the 'The Changing Wealth of Nations' Report (http://data.worldbank.org/data-catalog/wealth-of-nations). Data available for Australia was extracted from the Australian Bureau of Statistics (ABS, 2013), while for the United Kingdom data was obtained from the Office of National Statistics (ONS 2013a, 2013b, and 2014). These last two accounting reports are referred to as SEEA-AU and SEEA-UK.

Natural Capital Accounting Frameworks

Chapter 4 of this study approaches research question 1. "*What are the differencing valuation approaches of the selected natural capital accounting frameworks (IWI, CWI, SEEA)?*".

Data used in section 4.3 to compare IWI and CWI natural capital values was adjusted to represent the estimated value in US dollars of the year 2000. It is also important to note that the values shown in the bar charts are summations of the assets common to both accounting systems. Hence, the value of fisheries and protected areas were excluded from the estimates provided by IWI and CWI respectively. The graphs in this section will help visualize trends and discrepancies indicated by the different frameworks. In section 4.4 value differences between the accounting frameworks generated by methodology alone will be highlighted. Furthermore, expected value outcomes of the different methodological approaches employed by the selected natural capital accounting frameworks, and the potential flaws compared to real-world values are identified. Potential over- and under- estimates as compared to likely future scenarios will be identified. In section 4.5, Australia, Brazil, South Africa, and United Kingdom were selected as case studies, allowing for the comparison of numerical data used at the level of individual natural capital assets. This facilitates the analysis of value discrepancies both from a methodological perspective and as the impact of using different data sources. The methods used to answer this question are quantitative and qualitative. On one hand, direct numerical comparisons were made of the values determined by the accounting frameworks and the expected outcomes of the use of specific equations (methodologies). On the other hand, plausible future scenarios are considered to identify potential flaws in the approaches to natural capital valuation considered in this study.

Accounting for Non-marketed Ecosystem Services

Chapter 5 answers research question 2, "*Would the inclusion of non-marketed ecosystem services, as valued across studies available in TEEB database, lead to significant changes in the total natural capital value determined by the natural capital accounting frameworks (IWI, CWI, SEEA)?* ".

In order to determine the importance of including ecosystem services that are not yet considered in the wealth accounts, the proposed research used data provided by TEEB (van der Ploeg et al., 2010) to estimate the value of individual ecosystems and to add them up for four individual countries (Australia, Brazil, South Africa, and the UK). Caution was taken in avoiding the inclusion of marketed ecosystem services values that are already included in the natural capital accounting frameworks. For this reason, only some of the TEEB studies were included in the calculations (see Annex 2). All TEEB values used in this study were transformed to USD of the year 2000, before being added up and compared to the natural capital accounting values.

In order to determine the value of the future flows of benefits from these ecosystems, the equation below was used:

$$V_t = F\left(1+\frac{1}{r}\right)\left(1-\frac{1}{(1+r)^T}\right) \quad (3.1)$$

This equation represents a simplified version of the Net Present Value (NPV, explained in Chapter 4.2) for the special case in which the value of annual rent (flow, F) is assumed to remain constant. The equation can be obtained using sum series for NPV. T is the lifetime, or the duration of benefiting of the given service, while r is the discount rate. The flow was determined as the sum of all selected ecosystem services values in a given country. The individual ecosystem services values were determined by multiplying the monetary valuation of benefits per unit area by the total area of the ecosystem at stake. Some values were already provided as annual flows, while others as benefits per households and were multiplied by the number of households involved. It is also important to notice that, although certain ecosystem services types appear multiple times, they refer to distinct ecosystems. Additionally, the TEEB ecosystem services values are provided for distinct years, and they have been solely summed up on the assumption that these benefits values will remain the same over time.

For a better comparison of the compiled TEEB flow values to the natural capital accounting values, specific variable values have been applied in equation 3.1. To compare TEEB values to CWI values, the discount rate was set to 4%, and the lifetime to 25 years, which are typical values used in CWI. The resulting ecosystem services future flow value was referred to as TEEB-CWI. The same treatment was applied for comparison to SEEA-AU, referred to as TEEB SEEA-AU. In order to compare to IWI, a new value was determined and used under the acronym TEEB-IWI, where the discount rate is 5% and the lifetime is infinite. SEEA-UK uses discount rate that decreases over time. However, the first change occurs after 70 years, while the adopted lifetime is 25 years (by SEEA-UK). Hence, a discount rate of 3.5% and a lifetime of 25 years was used to determine the value of TEEB SEEA-UK.

The value of the future flows of benefits from these ecosystem services was compared to the natural capital accounting values, while maintaining awareness of the fact that these are only local values (from individual ecosystems), and not national values (scaling up these values to a national level may not produce reliable estimates and it was avoided). If studies of all ecosystems and their services were available for the given countries, the values would be expected to be significantly higher.

Loss and degradation of natural capital

Chapter 6 of this study deals with research question 3, "*Are there numerical or methodological correlations between natural capital accounting value changes and environmental costs (lost natural capital and externalities) determined over a given period of time by ANS and GPI?* ".

In order to identify potential correlations between the natural capital accounting frameworks and ANS and GPI, the evolution of these indicators over the period 1995-2005 has been analysed for five countries – Australia, China India, Japan, and the USA. The values for ANS and GPI were determined by including only the items concerning the environmental aspect. The individual items were summed up and the value was transformed to USD of the year 2000. In order to answer the third research questions, the value changes in natural capital (from accounting frameworks) will be compared to the values of ANS and GPI. This will be performed at the value aggregate level, as well as the level of individual items composing the indicators.

3.2 Sample choice

This thesis will make use of data for a relatively small number of countries – 19 countries, with an emphasis on 8 countries to answer different research questions. This sample size was chosen as a result of data availability for the different natural capital accounting frameworks and indicators.

The 19 countries sample consists of: Australia, Brazil, Canada, Chile, China, Colombia, Ecuador, France, Germany, India, Japan, Kenya, Nigeria, Norway, Saudi Arabia, South Africa, United Kingdom, United States, and Venezuela. These and the Russian Federation are the only countries for which IWI values were provided in the Inclusive Wealth Report (UNU-IHDP, 2012). However, the Russian Federation was excluded because there was no data available for CWI.

Out of the list of countries given above, 4 countries have been selected for more detailed analysis to answer research questions 1 and 2: Australia, Brazil, South Africa, and United Kingdom. Australia and the United Kingdom are the only countries for which SEEA was used to cover a large variety of natural capital assets. In order to answer the final research question, Australia, China, India, Japan and the United States were selected. The reason behind this choice is, once more, data availability.

Although the sample size might appear to be small, it is in fact sufficient for the general assessment that this thesis aims to conduct. The methodology of the natural capital accounting systems is considered to be the main object of assessment in this research. Therefore, the data on different countries only serves as case studies, for comparison on the magnitude of discrepancies that the difference in methodology and data use can generate. Furthermore, this research ensures a high reliability and validity of data by making use of the results provided on the official websites or in the scientific works of the developers of the natural capital systems (CWI, IWI, GGI, ANS, GPI, TEEB).

Nonetheless, this sample size poses some limitations in exemplifying the results produced by the different accounting methods. One such important limitation is the imbalance between the number of rich and poor countries. Out of the entire list of countries, only Kenya classifies as a low income country, and only India and Nigeria represent the lower middle income group. All other countries pertain to the middle income and especially to the high income groups. Therefore, the sample shows a clear bias towards the richer countries. Table 1shows the World Bank (2012b) classification by income of countries assessed in this study.

Table 1 Classification by income of countries assessed in this study (World Bank, 2012b)

Low income	Lower middle income	Upper middle income	High income
Kenya	India Nigeria	Brazil Chile China Colombia Ecuador South Africa Venezuela	Australia Canada France Germany Japan Netherlands Norway Saudi Arabia United Kingdom United States

Chapter 4. Natural Capital Accounting Frameworks

A Comparative Analysis of SEEA, CWI, and IWI

4.1 Introduction

In this chapter, the focus will be placed on natural capital accounting as framed in three accounting systems – Comprehensive Wealth Index (CWI), Inclusive Wealth Index (IWI), and System of Environmental-Economic Accounting (SEEA). A brief description of these accounting systems is given below.

Comprehensive Wealth Index (CWI)

The World Bank first published the CWI methodology and country-specific data for 120 countries in '*Where is the wealth of nations?*' (Hamilton et al. 2006) followed by an updated version, '*The changing wealth of nations'* (Jarvis et al. 2011). Realizing the difficulty in estimating total wealth by adding up the values of individual capital assets, the World Bank employed a top-down approach. Hence, the total wealth was first determined as the present value of future consumption, and three individual asset types were later constructed to add up to this wealth. In the CWI, consumption is given by spending on market goods and services, plus the investments in capital assets. Nonetheless, this approach assumes that current consumption levels can be sustained indefinitely.

The three CWI asset types are: produced capital, natural capital, and intangible capital. While the first two asset types are built determined from available data, the third asset type, intangible capital, is seen as a residual (total wealth minus the value of produced and natural capital). Hence, intangible capital includes mostly human and social capital, but it also accounts for produced and natural capital that was omitted in the individual estimates for these asset types. Using this approach ensures that total wealth is not underestimated as a result of lack of data.

Inclusive Wealth Index (IWI)

UNU-IHDP and UNEP published the methodology of IWI and country-specific findings related to this indicator in the '*Inclusive Wealth Report 2012'* (UNU-IHDP & UNEP, 2012). IWI is based on the definition of wealth as the social value of an economy's assets. Contrary to CWI, IWI does not start from a predetermined wealth value (as in a top-down approach), but rather builds this wealth value by summing up the individual assets values determined (bottom-up approach) - human capital, produced capital, and natural capital (health and time are two additional capital assets, but they are measured separately).

IWI closely follows the methodology developed by Arrow et al. (2012). However, new assets are also included, such as coal and fisheries. The methods used to build up this index also draw upon the CWI methodology. However, the theoretical framework is deeply revised, and different approaches are employed in the methodology of asset valuation. At a theoretical level, the CWI starts with the assumption that wealth is given by the discounted flow of consumption. Hence, a sustainable path would imply maintaining this flow at a constant or increasing level. In contrast, in IWI, wealth is defined as the social worth of the asset base (at shadow prices), and any change in wealth would be directly linked to a change in the asset base. However, lack of data availability leads to difficulties in determining the real social worth, and as a consequence, shadow prices were replaced with market prices for the purpose of asset valuation. Both accounting systems aim to measure sustainability, but in different manners. This also has implications on the methodological approach. For some assets, IWI changes the general focus in accounting from flows (income), as used in CWI, to total stocks (wealth).

System of Environmental-Economic Accounting (SEEA)

The System of National Accounts (SNA) represents international guidelines that standardize national accounting, created by the United Nations in 1953. However, this system was not created to accommodate complete environmental accounting. The SNA was only limited to environmental goods and services that are marketed, their value was taken as their exchange values, while depletion of natural resources was not accounted for (Obst & Vardon, 2014). The Systems of Environmental-Economic Accounting Central Framework (SEEA-CF) was created as a satellite of the SNA along with SEEA –Experimental Ecosystem Accounting framework as guidelines (developed later), in order to overcome the limitations in environmental accounting. SEEA was first published in 1993 (United Nations, 1993), appearing in its final version in 2012 (United Nations, 2012a). Contrary to the SNA, SEEA concerns accounting in both monetary and physical terms, hence including environmental goods and services that are not marketed. However, in monetary terms, SEEA maintains the approach by which the value of natural assets is given by their exchange value, hence excluding consumer surplus and non-marketed goods and services. SEEA also records depletion and degradation, through the changes in physical terms that impacts on monetary valuation. Furthermore, expenditure on environmental activities such as environmental protection, restoration, and management are also taken into account in the functional accounts, but this would not be discussed here, as it does not impact on the value of natural capital assets.

For the purpose of this study, national data available for Australia (Australian System for National Accounts, developed by the Australian Bureau of Statistics) and the United Kingdom (National Environmental Accounts, developed by the Office of National Statistics) were used and presented under the names SEEA-AU and SEEA-UK, respectively. These two countries produced national accounts based on the SEEA-CF approach.

4.2 Summary of methods used by CWI, IWI, SEEA-AU and SEEA-UK

This section provides a complete summary of the methods used by each accounting framework for the common natural capital assets. The information in this section was extracted from the main scientific works concerning the three accounting frameworks (CWI, IWI, SEEA) - Hamilton et al. (2006), Jarvis et al. (2011), UNU-IHDP & UNEP (2012), and United Nations et al. (2012a) - and the reports by the Australian Bureau of Statistics (ABS, 2013) and the UK Office for National Statistics (ONS, 2014). References are provided where other sources were used.

This summary only covers the natural capital assets that the three accounting systems share in common: mineral and energy resources, forest resources, and cropland and pastureland (agricultural/cultivated resources). Table 2 provides a detailed list of all the natural assets covered by CWI, IWI and SEEA.

Table 2 Natural assets considered in the three natural capital accounting frameworks. The assets marked with 'X' are included in the respective accounting system

Natural Assets	CWI	IWI	SEEA
Mineral and energy resources	X	X	X
Timber resources (forests)	X	X	X
Non-timber forest resources	X	X	
Crop land	X	X	
Pasture land	X	X	
Protected Areas	X		
Fisheries		X	
Other soil resources/inputs			X
Land			X
Aquatic resources			X
Other biological resources			X
Water resources			X

4.2.1 Net Present Value – Shared approach

All three accounting systems make use of the net present value (NPV) as an approach to determine the total wealth corresponding to certain assets. The equation below shows the NPV of an asset in year t.

$$NPV_t = \sum_{i=t}^{t+T} \frac{RR_i}{(1+r)^{i-t}} \tag{4.1}$$

Where *t* is the year for which the NPV of the asset is calculated, *r* is the discount rate, RR_i is the resource rent in year *i*, and *T* is the asset lifetime. Although the three systems use the same approach, they apply different assumptions, and hence, different values for each of the variables in the NPV equation. Furthermore, for some resources, other methods are also employed. In the case of fossil fuels, mineral resources and timber, IWI does not calculate the NPV assuming an annual flow of production, but rather determines the in-situ value of the entire resource by multiplying resource rents and stocks.

CWI applies the NPV approach for all types of natural assets and uses lifetimes of 25 years or less (for unsustainably harvested forests). On the other hand, IWI only uses NPV in determining the wealth from cropland, pastureland and non-timber forest resources. When the NPV approach is used, IWI takes an infinite lifetime, hence assuming sustainability of the use of those resources. SEEA recommends the use of NPV for all natural capital assets. However the lifetime of the asset varies depending on considerations such as available stock, assumed extraction and growth rates (in the case of renewable resources). SEEA-AU and SEEA-UK follow these guidelines, with a few exceptions. For instance, in the case of coal and mineral resources, SEEA-UK uses a fixed lifetime of 25 years.

The discount rates used by CWI and IWI are fixed, 4% and 5% respectively. SEEA recommends a discount rate that applies to the owner of the asset, and not to society at large. Such a discount rate would be larger than the later. SEEA-UK uses a declining discount rate which starts at 3.5% and declines to 1% in 5 steps over a period of 300 years (taken from the HM Treasury, 2003, page 100). On the other hand, the Australian National System of Accounts (ASNA), SEEA-AU, uses a general discount rate of 4%.

The resource rents are used directly from primary sources or estimated, given available sources, by both CWI and IWI. The approach used by all three systems is the residual value method (price minus cost). Once the unit resource rent is determined, the total resource rent is calculated by multiplying the unit rent with the total production/extraction. SEEA gives clear guidelines on how to calculate resource rents, and the two accounting reports discussed (SEEA-AU and SEEA-UK) here both follow these steps and use country specific data (from national statistics institutes). For future resource rents, SEEA recommends the projection of a constant annual extraction flow and no price changes. This approach is also followed by the other systems in most cases. However, SEEA highlights the importance of considering impacts of depletion, degradation and new discoveries on the price. These changes should be valued using in situ resource prices.

The following sections present in detail the methods used by the different natural capital accounting frameworks for each individual natural capital asset that show overlap: energy and mineral resources, forests, cropland, and pastureland.

4.2.2 Energy and mineral resources

The energy resources are fossil fuels owned by the given country: oil, natural gas, coal. The minerals (metals/non-metals) considered by each of the three systems are shown in Table 3. The methods used by each of the three national capital accounting frameworks are described below. The data sources used by each accounting framework are shown in

Table 4.

Table 3 Minerals and metals considered

IWI	CWI	SEEA		
		UK	AU	
Bauxite	Bauxite	Lead	Bauxite	Platinum
Copper	Copper	Silver	Copper	Cobalt
Gold	Gold	Peat	Gold	Uranium
Iron	Iron	Salt	Iron Ore	Cadmium
Lead	Lead	Gravel	Lead	Rare earths
Nickel	Nickel	Limestone	Nickel	Lithium
Phosphate	Phosphate	Chalk	Silver	Magnesite
Silver	Silver		Tin	Ilmenite
Tin	Tin		Zinc	Rutile
Zinc	Zinc			Zircon
				Antimony
				Diamonds

Table 4 Energy and Mineral Resources - Data Sources[i]

Variables	CWI		IWI		SEEA-UK		SEEA-AU	
	Fossil Fuels	Minerals	Fossil Fuels	Minerals	Fossil Fuels	Minerals	Fossil Fuels	Minerals
Reserves	BP (2006) & USEIA (2006)	USGS (2006a&b)	USEIA (2011)	USGS (2011)	ONS (2010)	BGS	GA	GA
Price	WB Estimates [ii]	WB Estimates [iii]	BP (2011) - averages	USGS (2011) WB (2011)	ONS; BGS; HM R&C; OBR	BGS; HM R&C	AFR, BREE	AFR, BREE
Extraction	BP (2006) & USEIA (2006)	USGS (2006a&b)	USEIA (2011)	USGS (2011)	ONS (2013); BGS; OBR	BGS	ABS, BREE	ABS, BREE
Rental Rate	WB Estimates [iii]	WB Estimates[iii]	N&W(2008)	N&W(2008)	ONS; BE	Unclear	private firms	private firms

Comprehensive Wealth Index

The assumption of zero growth rate of rents was applied hence, maintaining constant total rents and constant extraction path over the lifetime of the resource. In order to determine an estimate of the resources lifetime, reserves to production ratios (stock/yearly extraction = lifetime) have been computed for all countries for different resources. The values that were found mostly lied between T=20 and T=30, with the exception of very abundant coal, bauxite and iron (which had reserve-to-production ratios of over 120 years). However, the value used in the CWI is T=25 for all types of minerals and energy resources.

Inclusive Wealth Index

IWI covers the same energy and mineral resources as the CWI (see Table 3). The wealth attributed to these resources was calculated by multiplying reserves and unit rents. The reserves in each year were determined by setting the base reserve at the level that was available in the year 2008, and calculating the stock of the previous years (t = 2008, 2007…1990) as follows:

$$Stock_{t-1} = Stock_t + Extraction_t \qquad (4.2)$$

System of Environmental-Economic Accounting – United Kingdom

SEEA-UK applies the NPV and includes both proven (>90% chance of extraction) and probable (>50% chance of extraction) reserves. Future resource rents that were used in the calculation were determined as a 5 year average of actual data of prices minus costs (from the years previous to the current year). This value was assumed to be constant for the rest of the asset lifetime. However, actual data is used for values up to 2011. Future extraction is also based on projected values, taking a 5 year average (hence, assuming a constant extraction path) for all resources, except peat. Peat oil extraction was assumed to be diminishing exponentially over its lifespan.

Except for coal, the lifetime of fossil fuels is determined depending on the projected extraction paths (ONS, 2013a). These extraction paths have been set according to the Office for Budget Responsibility (Forecasts, Economic Fiscal Outlook, http://budgetresponsibility.org.uk/) forecasts of production and incomes, derived from the price of interest rate swaps, given the market expectations of the forecast period. Hence, the asset life was calculated as years to depletion, assuming the projected extraction path. Nonetheless, the lifetime for coal and mineral resources is fixed, 25 years, due to lack of data availability. In order to determine the unit value for minerals, the export volume was divided by the total export value.

System of Environmental-Economic Accounting – Australia

The economic rent emerging from the exploitation of minerals and fossil fuels has been derived as the future flow of income per year, discounted appropriately throughout the entire predicted life of the mine (NPV approach). In order to account for potential changes in prices, costs, and production, SEEA-AU used 5 year average values (over years previous to that for which the value is calculated) for these three variables. The resources considered in the calculations were the proven and the probable mineral and energy resources (economic demonstrated resources, EDR). Then average life-times of mineral resources during the period 1995-2005 vary from very low values such as 4.7 years (Diamond), 15.4 (Tin), and 18 (Gold), to very high values, 866 (Magnesite). For the energy resources, there is also a broad variation from 8.7 years for crude oil to 665 years for brown coal.

4.2.3 Forests

This section is concerned with the different approaches in valuing the different goods and services that forests provide. This value was split by IWI and CWI into timber and non-timber values, while SEEA-UK and SEEA-AU only consider timber value. The data sources used by each of the accounting systems are provided in Table 5.

Table 5 Data resources for timber valuation[iv]

Values	IWI	CWI	SEEA-UK	SEEA-AU
Forest stocks	-	FAO (1995; 2001; 2006; 2010)	FC	N/A
Commercially available forest stock	50km from infrastructure	FAO (2006)	N/A	ABARES
Wood production	FAOSTAT	FAO (2011)	N/A	ABARES, AFG
Value of wood	FAOSTAT	FAO (2011)	FC (2013)	ABARES, AFG, forest industry
Rental rate	World Bank Estimates[v]	Bolt et al. (2002)	N/A	AFG, forest industry
Forest area	FAO (1997; 2000; 2001; 2006)	FAO (2011)	FC	ABARES

Timber value

Comprehensive Wealth Index

CWI calculates the wealth from timber resources as the NPV of rents from roundwood production. The value of standing forest was set as the discounted stumpage price, minus the price of raising the forest. Since the stumpage prices are usually not available, the unit rent was determined as the product between a composite weighted price (PUT_t) times the rental rate. Composite weighted price of standing timber is determined from the following prices (P_{kt}) weighted by production (Q_{kt}): 1) export unit value of coniferous industrial roundwood; 2) export unit value of non-coniferous industrial roundwood; 3) estimated world average price of fuelwood. The composite price per unit timber equation is shown below, where k gives the wood type, and Q_{kt} is the total production.

$$PUT_t = \frac{1}{Q_{total}} \sum_k Q_{kt} \cdot P_{kt} \tag{4.3}$$

The forests available for wood supply were defined as forests within 50km of infrastructure. The production and the unit export value are taken as averages over 5 years and maintained constant throughout the asset lifetime.

The lifetime over which the resource stream is capitalized is given by the difference between the harvest and annual natural growth levels. The lifetime T is 25 years if the harvest is equal or lower than the increment, in which case the harvest is considered to be sustainable. In the opposite scenario, the lifetime is given by the forest volume divided by the difference between production and increment.

Inclusive Wealth Index

In IWI, the total timber wealth was calculated as the rental price multiplied by the total volume of timber commercially available (forest area x timber density x percentage commercially available) every year. Similar to the method used by CWI, the price per unit of timber was determined as a weighted average of industrial roundwood and fuelwood using values prom production and exports. The average price was taken over the entire study period (1990-2008), and rental rates were assumed to be constant over time.

System of Environmental-Economic Accounting – United Kingdom

In this valuation method, all timber resources (not only those commercially available) from the UK have been included (ONS, 2013b). The standing forest average price was used as a mean of in-situ valuation. The stumpage price is used as unit resource rent, taking a 5 years average (2 years before the current year, 2 years after and the current year), and maintained constant for future income. SEEA-UK employs a classification of timber given by the age of the forest, and selects a harvesting age of 50 years. Woodlands of the age of 50 or more are valued at harvesting prices of the current year. However, for younger forests appropriate discounting is applied, given by the time it takes to reach the harvesting age (50-current age). All these values are summed up in order to obtain the NPV of the current year. Given that the currently young forest will grow in density until the harvesting time, a constant timber volume was maintained for all forest areas (304 m^3overbark/hectare).

System of Environmental-Economic Accounting – Australia

When valuing forests, Australia made a clear distinction between plantations and native forests, and excluded from the valuation all forests that are under conservation law or where logging is forbidden. Given that no market price data was available for the native forests standing timber, SEEA-AU used the NPV of future royalties income over the rotation cycle of the forest. This method assumes that royalties represent a good estimate of the economic rent that would be obtained from felling. The cost of borrowing to the forest industry was used as a nominal discount rate. This cost was estimated as a five-year lagged average, using data provided in the Statistical Tables of the Reserve Bank of Australia. The real rate of discount was derived from an index reflecting price changes in the forest industry.

In the case of plantation forests, insurance values by tree age have been used as an estimate of the market value. In this case, the Australian Forest Growers'Association (AFG) provides insurance schedules showing the value of each hectare given the rotation cycles: 1 to 30 years for coniferous plantations and up to 20 years for broadleaved plantations.

Non-Timber value

Comprehensive Wealth Index

The CWI also accounts for non-timber benefits from the forest, such as hunting, recreation, watershed protection, option and existence value. The monetary value of such benefits per hectare was taken from Lampietti & Dixon (1995) and Merlo & Croitoru (2005) ranging from US$113.7 in developed countries to US$23.8 per hectare in developing countries (USD of the year 2000). Lampietti & Dixon (1995) determine the median values of different non-timber forest benefits (minor forest products, hunting and fishing, watershed effects, recreation, and option and existence value) from the existing literature (up to year 1995). Their findings show that non-timber value is 145 USD/ha in developing countries and 190 USD/ha in developed countries, valued in US$ of the year 2000. Merlo & Croitoru (2005) use the total economic value (TEV) approach comprising numerous non-timber goods and services of use, option, and non-use values (grazing, non-wood forest products, recreation, hunting, water and watershed protection and degradation, carbon sequestration, option, bequest and existence value of biodiversity). Methods such as contingent valuation, travel cost, substitutes prices, and direct market prices were used, and the average value obtained was of 133 euros/ha of the year 2001. It is unclear how the values in CWI were derived from these two scientific papers.

It was assumed that only 10% of the forest area is accessible in each country. The rate of deforestation is also accounted for. The lifetime used for the NPV was 25 years in this case as well.

Inclusive Wealth Index

The IWI uses the same method, with values extracted from Lampietti and Dixon (1995) of US$190 per hectare for developed countries and US$145 for developing countries applied to 10% of the forests (see CWI section above for more details). Nonetheless, the total wealth from non-timber resources is capitalized over an infinite time period.

Note: SEEA-UK and SEEA-AU do not account for non-timber value.

4.2.4 Agricultural assets

IWI and CWI define agricultural assets in terms of agricultural land value, and differentiate between cropland (land dedicated to growing plant resources) and pastureland (land used for grazing). On the other hand, in SEEA-UK and SEEA-AU the distinction between animal and plant resources is less clear, the total value of these assets being estimated as an aggregate. Table 6 below presents the different data sources that were used by each accounting systems.

Table 6 Data used for agricultural land valuation[vi]

Values	CWI	IWI	SEEA-UK	SEEA-AU
Quantity produced	FAO prodSTAT	FAOSTAT	ONS	REACS, ABS
Price of crops and animal products	WB; FAO tradeSTAT	FAOSTAT	ONS	ABS
Rental Rate	Dimaranan, 2006	N&W (2008)	ONS	ABS
Harvested Area	FAO prodSTAT	FAOSTAT	ONS	N/A
Cropland Area	N/A	FAOSTAT	ONS	N/A
Pastureland Area	N/A	FAOSTAT	ONS	N/A

Cropland

Comprehensive Wealth Index

In CWI, the value of agricultural land was estimated based on present discounted values of land rents, assuming world prices. Agricultural land rates were calculated as the market value of crop production multiplied by the rental rate. The unit rent was assumed to be fixed at 30% of the unit price for all countries and crops considered. The crops considered in this report are: cereals, fruits, nuts, oil crops, pulses, starchy roots, stimulants, sugar crops, and vegetables. Yields and unit-export values were determined as averages over 5 years (1991-95 for 1995; 1996-2000 for 2000; and 2001-2005 for 2005). The area harvested is that of the year analysed (1995, 2000, or 2005).

The average rental price in year t is given by:

$$RC_t = \sum_k 0.3 \cdot Y_{kt} \cdot A_{kt} \cdot P_{kt} \qquad (4.4)$$

Where k = crop type, Y=yield, A= harvested area and P=world price. The wealth associated with crop land in a given country at a given time, t, is therefore:

$$WC_t = \sum_{x=0}^{24} \frac{(1+g)^x \cdot RC_t}{(1+r)^x} \tag{4.5}$$

Where g is the growth in production, and g=0.97% for developed countries and g=1.97% for developing countries, as estimated by Rosengrant et al. (1995) based on expected future research, and expected educational, technological and market developments. Land areas are assumed to remain constant over time.

Inclusive Wealth Index

A similar approach is used by IWI as well. However, IWI weights over 159 representative crop types.

$$RCA_t = \frac{1}{AC} \sum_{k=1}^{159} R_k \cdot P_{tk} \cdot Q_{tk} \tag{4.6}$$

Where, AC is the harvested area, R is the rental rate, as determined by Narayanan & Walmsley (2008), P is the price per unit produced, Q is production.

Hence, the average value of the total wealth per hectare per year for country i, determined over 19 years (1990-208) is given by:

$$\overline{Wha} = \frac{1}{19} \sum_{t=1990}^{2008} \left(\sum_{x=0}^{\infty} \frac{RCA_t}{(1+r)^x} \right) \tag{4.7}$$

The total wealth encompassed by agricultural land at time t is

$$WC_t = \overline{Wha} \cdot AC_t \tag{4.8}$$

Pastureland

Comprehensive Wealth Index

Similar to cropland, the method for pastureland assumes the returns to represent a fixed percentage (in this case, 45 percent) of the value of output. The value of output was based on the production of meat, milk, and wool, valued at international prices. This is further applied to specific country outputs and valued at world prices. The equations used for pastureland are the same as for cropland, but Y*H are replaced by the production of the pastureland. The growth in production for pastureland was set as 0.89 percent in developed countries, and 2.95 percent in developing countries. These production growth rates were taken from Rosengrant et al. (1995) for both pastureland and cropland.

Inclusive Wealth Index

Confronted with the challenge of linking price and production data availability to a given land surface, IWI assumed that the rents per hectare of pastureland are the same as those of cropland. Hence, the wealth stemming from pasture land is identified as:

$$WP_t = \overline{Wha} \cdot AP_t \tag{4.9}$$

Where AP is the pastureland area at time t.

SEEA Approach

System of Environmental-Economic Accounting – United Kingdom

In SEEA-UK crops, animal products, and hunting and related service activities are aggregated into one asset - 'agricultural land'. The wealth of this aggregate was determined by means of the NPV method applied to the product of rents and production, over a period of 25 years. Real data was used up to year 2011 and constant rents (of the year 2011) were assumed for future year projections. It is relevant to note that wages of the owner-occupier of the farms are not subtracted.

System of Environmental-Economic Accounting – Australia

SEEA-AU aggregated most agricultural assets under the more general asset 'cultivated biological resources'. Cultivated biological resources comprise of livestock (sheep, cattle, horses, etc.) used repeatedly for breeding, recreation, or to obtain products such as milk, wool, etc., as well as trees, crops, and other plant resources that generate natural resources under the direct control and management of an institutional unit. More work still needs to be done in order to include natural resources that produce a single output (e.g. livestock slaughtering for meat, cut down trees).

Plant resources in the SEEA-AU include grains, fodder and grass, plants and flowers, fruits, nuts, vegetables, sugar cane, cotton, wine grapes, hopes, tobacco, and others. Their value was determined as prices multiplied by quantities, from which the input costs have been extracted.

Animal production has been derived as a product of prices and quantities, from which the input costs has been extracted. The livestock products included are: meat (sheep, lamb, cattle and calves, pigs, deer, poultry for slaughtering and egg laying hens), pets and live animals, milk, eggs, honey, and agistment of horses, sheep, and cattle. Furthermore, SEEA-AU also accounted for the decline in efficiency with the maturation of animals. This is described by the age-efficiency function, of hyperbolic shape. The assumption behind this model is that the efficiency of an asset declines as the product becomes older, initially at a slow rate, and later at a higher decline rate. From this age-efficiency function, an age-price function can be derived, using an average age-efficiency value and a real discount rate. The age-efficiency function is given below:

$$E_t = \frac{M - A_t}{M - b * A_t} \tag{4.10}$$

where E_t is the efficiency of the asset at time t (ratio of the asset's efficiency when new), M is the mean asset life, A_t is the age of the asset at time t, and b is the efficiency reduction parameter. The value of the efficiency parameter reduction for livestock is 0.5, as the immature years are not taken into account. The mean asset lives vary from six (e.g. for wool sheep) to ten years (e.g. for dairy cattle). The mean asset lives have been extracted from different industry bodies data (Bureau of Rural Sciences, Woolmark Company, Dairy Farmers Corporation, and Meat and Livestock Association).

4.3 Case studies – Australia, Brazil, South Africa, United Kingdom

For a more in depth analysis of the natural capital accounting frameworks, comparing the impact of both methodology and use of data, four countries were selected as case studies: Australia, Brazil, South Africa, and United Kingdom. Australia and United Kingdom have been selected primarily due to existing data generated by means of SEEA methodology as well as the other two accounting frameworks. However, countries were also selected based on the results of the comparative plots of IWI and CWI provided in

Annex 1. For instance, Australia could be seen as representative of the countries where the differences between CWI and IWI values are significantly high. Likewise, the United Kingdom represents countries where CWI does not show a clear trend along the 10-year period (value in 2000 higher than the other two values). Brazil and South Africa were selected as examples of countries where, although IWI provides relatively stable values, CWI shows strong increase or decrease in values (respectively) over the ten year period. In addition to these representative characteristics, the four countries selected for analysis are also well balanced in terms of development – two developed countries and two developing countries.

Tables 7 and 8 show the total monetary value of natural capital assets as provided by each accounting framework for the four different countries. As SEEA-UK and SEEA-AU do not account for non-timber value of forest resources, the comparison is made between total asset values that exclude this source of income (also excluded from the values provided by CWI and IWI) in the case of Australia and UK. On the other hand, the natural capital assets values of Brazil and South Africa are complete (include non-timber value).

Table 7 Total monetary value of natural capital assets, excluding non-timber value, in billions of US$ of the year 2000

Australia			
Year	**1995**	**2000**	**2005**
CWI	399	579	600
IWI	1,912	1,873	1,825
SEEA-AU	106	113	206
United Kingdom			
Year	**1995**	**2000**	**2005**
CWI	282	3,343	290
IWI	152	132	113
SEEA-UK	308 (in year 2007)		

Table 8 Total monetary value of natural capital assets, in billions of US$ of the year 2000

Brazil			
Year	**1995**	**2000**	**2005**
CWI	1,302	1,862	2,310
IWI	1,447	1,425	1,409
South Africa			
Year	**1995**	**2000**	**2005**
CWI	453	351	237
IWI	526	509	492

This chapter will proceed by presenting the numerical results of each accounting method for the different natural capital assets. The discussion on the impact of methodology and data used in producing these results is provided in Chapter 7.1. The values in tables 7-11 were extracted from the main reports and data sets of the accounting systems (CWI, IWI, SEEA-UK, SEEA-AU) as presented in the methodology chapter, and adjusted for the currency of US dollars of the year 2000. These values cover the following natural capital assets: energy and mineral resources, forest (timber and non-timber) resources, and agricultural resources. Spot exchange rates from the Bank of England[vii] database and an inflation calculator (http://www.usinflationcalculator.com/) were used in this work to change the values from Sterling and Australian Dollars to US Dollars of the year 2000. Comparison of data used (e.g. reserves, production per year, price per unit) required data processing as a prerequisite (see Chapter 3 for methodology). The unprocessed data was obtained directly from the sources provided in tables 4-6 from Chapter 4.2.

Table 9 Monetary value of energy and mineral resources in million US$ of year 2000

Australia								
	Fossil Fuels				Minerals			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	68,045	85,893	200,549	-	61,783	81,702	163,944	-
IWI	1,202,237	1,176,921	1,145,927	-	96,575	90,678	84,222	-
SEEA-AU	44,061	47,220	106,908	-	23,079	26,572	54,538	-
Brazil								
	Fossil Fuels				Minerals			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	58,444	70,265	241,135	-	53,442	62,360	159,266	-
IWI	150,388	149,147	147,526	-	51,447	48,980	45,964	-
South Africa								
	Fossil Fuels				Minerals			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	29,982	25,537	77,976	-	26,436	16,081	33,253	-
IWI	411,078	397,266	382,391	-	25,958	23,163	20,815	-
United Kingdom								
	Fossil Fuels				Minerals			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	89,303	140,862	163,866	-	-	-	-	-
IWI	97,525	77,341	57,103	-	0.79	0.92	0.021	-
SEEA-UK	-	-	-	244,858	-	-	-	-

Table 10 Value of timber and non-timber resources in millions US$ of year 2000

Australia							
	Timber				Non-Timber		
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**
CWI	35,665	57,028	14,413	-	16,969	81,298	64,376
IWI	171,477	171,710	170,602	-	48,579	48,645	48,331
SEEA-AU	6,445	4,865	6,588	-	-	-	-
Brazil							
	Timber				Non-Timber		
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**
CWI	117,355	137,746	481,200	-	80,804	113,829	98,453
IWI	860,896	842,904	831,836	-	136,735	133,210	129,441
South Africa							
	Timber				Non-Timber		
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**
CWI	14,265	37,794	3,687	-	894	2,413	1,943
IWI	6,901	6,901	6,901	-	2,255	2,255	2,255
United Kingdom							
	Timber				Non-Timber		
Years	**1995**	**2000**	**2005**	**2012**	**1995**	**2000**	**2005**
CWI	10,631	29,452	8,446	-	3,252	3,044	2,580
IWI	17,117	17,899	19,695	20,598	848	877	893
SEEA-UK	-	-	-	8,570	-	-	-

Table 11 Agricultural land valuation in millions of 2000$US

Australia								
	Cropland				Pastureland			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	120,222	219,261	110,059	-	113,423	134,643	110,909	-
IWI	38,375	45,327	47,366	-	402,843	388,418	376,522	-
Brazil								
	Cropland				Pastureland			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	714,941	1,258,416	1,122,849	-	276,516	219,587	207,087	-
IWI	62,845	62,558	65,724	-	185,151	188,254	188,056	-
South Africa								
	Cropland				Pastureland			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	70,641	161,500	79,196	-	310,763	107,745	40,725	-
IWI	12,671	12,581	12,531	-	67,020	67,202	67,202	-
United Kingdom								
	Cropland				Pastureland			
Years	**1995**	**2000**	**2005**	**2007**	**1995**	**2000**	**2005**	**2007**
CWI	65,705	63,502	43,712	-	113,769	97,481	70,760	-
IWI	12,596	12,460	12,140	-	23,932	23,196	23,499	-

Chapter 5. Accounting for Non-market Values

Comparison of natural capital accounting frameworks with TEEB values

5.1 Introduction

Governments are becoming ever more aware of the need to include ecosystem services in the economic accounts, obtaining a complete picture of the real wealth provided by natural resources and ensuring well-informed policy making. Generally, determining the total economic value of ecosystems would imply taking into account the following components: direct use value (direct utilization, consumption), indirect use value (indirect, through externalities), option value (willingness to keep a resource that may be useful in the future), and non-use value (existence value, bequest value, altruism value). Although the direct-use value of provisioning services is in most cases reflected on the market, regulating and cultural services, in the form of indirect-use, option, and non-use value, are most often unaccounted for in monetary terms.

Only SEEA, out of the three accounting systems that are central to this thesis, incorporates ecosystems thoroughly, through the guidelines provided in SEEA-EEA (United Nations et al. 2012b). CWI and IWI include monetary valuation of non-marketed ecosystem services only for non-timber forest resources/services, but without providing a valuation methodology (the value is taken from the literature).

This chapter assesses the additional value that would be added to the values determined using CWI, IWI, and SEEA-AU/UK, if non-marketed ecosystem services valuation would be included. Unfortunately, no complete, national level, ecosystem services valuation data exists, but only studies of individual ecosystems and ecosystem services, using distinct methodologies. For this reason, the purpose of this chapter is to simply obtain a sense of scale, by summing up the existing studies (in TEEB database) for individual countries. Complete ecosystem services coverage, at a national level, would lead to a higher value of non-marketed ecosystem services than that provided in this study, under the restrictions imposed by data availability. For the purpose of this study, The Economics of Ecosystems and Biodiversity (TEEB) database was employed. In the following, this chapter will provide a brief overview of TEEB, followed by the results of the analysis on four countries (Australia, Brazil, South Africa, and UK), discussion and conclusion.

5.1.2 TEEB overview

The Economics of Ecosystems and Biodiversity (TEEB) is an outcome of the G8+5 countries environment ministers meeting in Potsdam, Germany, in March 2007. At this meeting, a decision was made to enable the analysis of the global economic benefit of biological diversity, the costs of biodiversity loss and that of taking effective measures to protect biodiversity. As a result of this decision, numerous valuable TEEB reports have been published with the help of various institutions and organizations. The TEEB initiative strives to deliver the economic tools that help determine the real economic value of ecosystem services, and promotes awareness and a better understanding of the real value of natural resources. TEEB's ultimate goal is to enable well-informed policies that promote biodiversity protection and lead to the achievement of the Convention on Biological Diversity objectives (TEEB, 2008).

From a structural perspective, TEEB identifies 12 main biomes (farther divided in various ecosystem types), and proposes a typology of 22 ecosystem services allocated to four main groups: provisioning, regulating, habitat and cultural amenity services.

TEEB recognizes that simple valuation is not a panacea for the environmental problems we face today, but rather sees it as a tool to improve our guide for economic decisions, which has so far led to prejudices for both human well-being and the environment. Lack of recognition of the real economic value of ecosystems and their complete spectrum of ecosystem services led to uninformed economic decisions and a misuse of natural resources (TEEB, 2010).

Van der Ploeg et al. (2010) created the TEEB database which incorporates a broad range of ecosystem valuations in the literature. In the following section, this chapter will proceed to compare ecosystem services values generated with the TEEB database, to the natural capital accounting value determined by CWI, IWI, SEEA-AU, and SEEA-UK. The purpose of this comparison is to develop an understanding of the magnitude of the TEEB estimate, as the consumer surplus that is not accounted for in the natural capital accounting frameworks.

5.2 Results

The countries selected as case studies for this chapter are the same as those analysed in Chapter 4.3 – Australia, Brazil, South Africa, and the United Kingdom. This chapter performs a comparison of the natural capital values provided by the natural capital accounting frameworks and a composite value of ecosystem services, as determined by means of the TEEB database. The purpose of this comparison is to obtain a better understanding of the importance of ecosystem services (not included in the main accounting frameworks) as an addition to the value of natural resources determined by the accounting frameworks.

Figure 1 presents the values determined by the natural capital accounting frameworks (CWI, IWI, SEEA-AU, SEEA-UK) next to the composite values obtained by using the TEEB database. A complete list of all the ecosystem valuations extracted from the TEEB database can be found in Annex 2. Some of the scientific papers provided in the TEEB database value the same type of ecosystem services. However, it was assumed that they are assessing ecosystems from different locations within the country, as surface areas do not coincide. The values of TEEB CWI, TEEB IWI, and TEEB SEEA-AU/UK were determined using the same NPV parameters as CWI, IWI and SEEA-AU/UK respectively. A detailed description of the methodology used in this chapter can be found in Chapter 3, in the section related to the use of TEEB data.

It is important to note that in the bar charts provided in Figure 1, although the value of IWI and CWI varies over time (1995, 2000, and 2005), the value of TEEB stays the same, as the valuation of individual ecosystem services were only determined for specific years and assumed to remain constant as an annual flow. In the bar chart for UK, this is also the case for the value of SEEA-UK, which only reproduces the value from year 2007 as a constant. This method of representation was chosen in order to have a good understanding of the time variations in CWI, IWI and SEEA-AU, and how these compare to the total values.

For Brazil and South Africa, total CWI and IWI values of natural capital accounting are shown. However, for Australia and the United Kingdom, the non-timber forest resources value was excluded from CWI and IWI, as SEEA-AU and SEEA-UK do not account for this value. This enabled a more accurate comparison across the natural capital accounting systems.

Two bar charts were created for Australia, one that includes the value provided by Blackwell (2006) for coastal ecosystem services, and one that does not include this value. The reason for producing two individual bar charts is that the addition from this scientific paper changes the results completely.

Blackwell (2006) obtained this ecosystem services value by taking the value provided by Costanza et al. (1997), and multiplying them with the total coastal area in Australia.

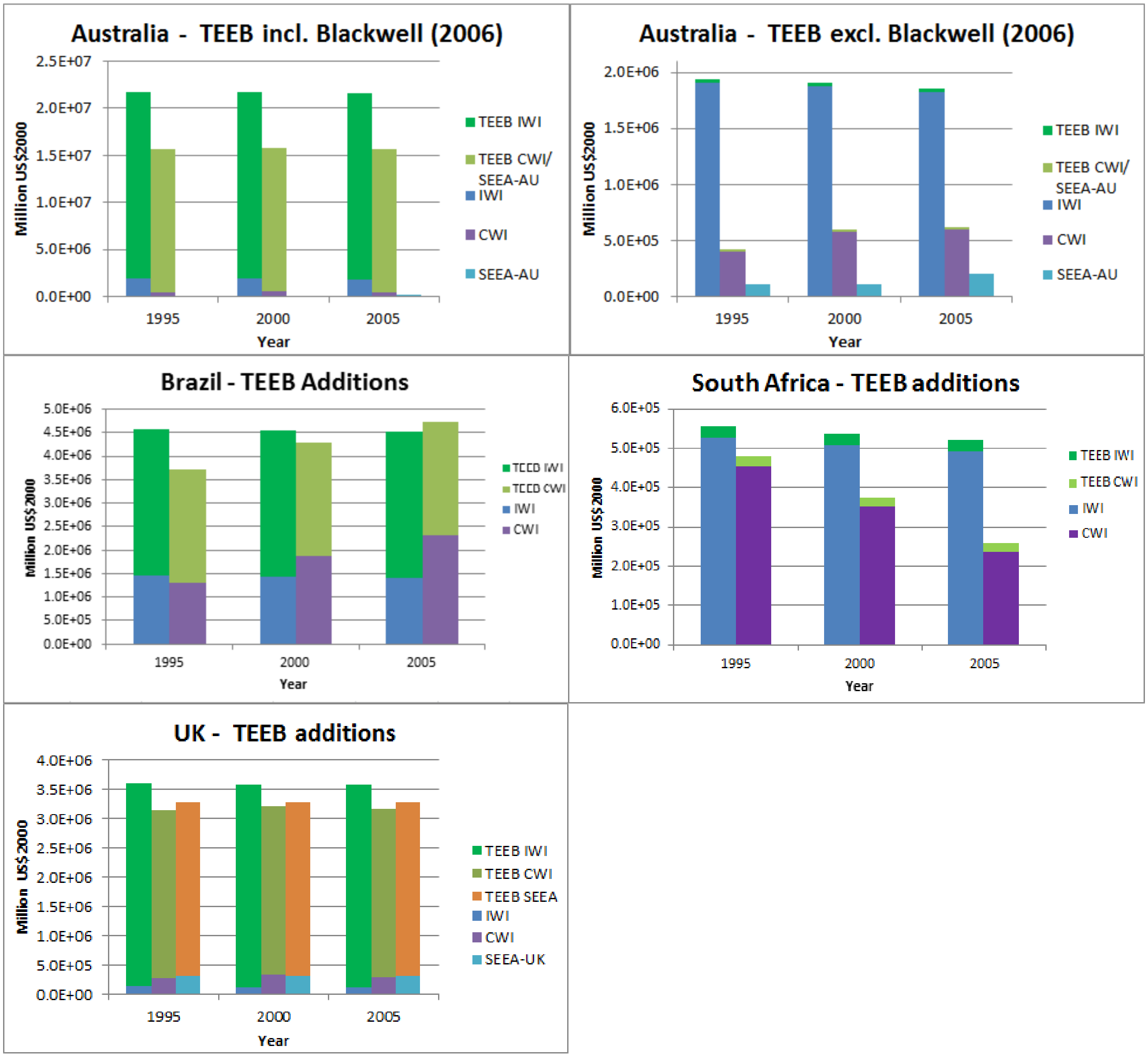

Figure 1 Comparison of natural capital accounting valuation (CWI, IWI, SEEA-AU, SEEA-UK) and TEEB non-marketed ecosystem services (TEEB IWI, TEEB CWI, TEEB SEEA) for Australia, Brazil, South Africa, and the United Kingdom. Australia is shown with TEEB ecosystem services value that include the valuation provided by Blackwell (2006) as well as valuation without this addition.

Chapter 6. Loss and Degradation of Natural Capital

GPI and ANS

6.1. Introduction

Two of the most important indicators that measure change in welfare are the Genuine Progress Indicator and the Adjusted Net Savings. These indicators combine environmental, economic and social aspects by identifying and valuing how economic activities impact (increase/decrease) on welfare.

Although both GPI and ANS are much broader indicators, in this work only the measures related to the environment are considered. All environmentally-related items in ANS and GPI have a negative welfare contribution as they represent costs to the society.

This section will proceed by describing the methodologies used by both ANS and GPI for the individual items included. In the second section of this chapter (6.2) a comparison of ANS and GPI against the natural capital accounting values will be presented over the period 1995-2005. Section 6.3 presents a discussion on the results, while the final section ends the chapter with the conclusions.

6.1.1 ANS and GPI methodologies

ANS methodology

ANS was created as an indicator of annual sustainability, suggesting a period of sustainable economic development when positive, or unsustainable development when having a negative value. However, in this study, only the environmental items of the ANS have been included – non-renewable resources (energy and mineral resources), forest resources, carbon emissions, and particulate matter -, and therefore, it no longer indicates sustainability, but only the variation in environmental costs over time (Bolt et al., 2002).

Non-renewable resources depletion values were determined as the total rent resulting from resources extraction during that year, as shown in equation 6.1 (Bolt et al., 2002). In ANS, non-renewable resources cover the same mineral and energy resources as the Comprehensive Wealth Index (CWI).

Rent =(Production Volume)(International Market Price - Average Unit Production Cost)* (6.1)

In the case of timber resources, an approach similar to non-renewable resources is adopted. However, for timber, only the extraction that exceeds the natural growth of forests is considered (roundwood production volume minus natural growth volume). Equation 6.2 (Bolt et al., 2002)shows the methodology for calculating this ANS item.

Rent = (Roundwood Exceedance Volume)*Average Unit Price*Rental Rate (6.2)

The social cost of carbon dioxide emissions was determined using a fixed marginal social cost per metric ton of carbon of $20 of the year 1995 (Fankhauser, 1994), that was deflated for the subsequent years using the USA GDP deflator (Bolt et al., 2002).

The final item considered by ANS is particulate matter emissions and it was determined as the willingness to pay to avoid mortality from this type of pollution.

GPI methodology

The items included on the GPI list, as well as the methodologies employed to determine their monetary values often vary between different studies. The data in this paper was collected from the studies in Lawn & Clarke (2008) for Australia, China, India, and Japan, and from Talberth et al. (2006) for the United States.

In the case of non-renewable resource depletion, the studies from Lawn & Clarke (2006) use El Serafy's user cost method (equation 2.4) described in Chapter 2.2. However, there are methodology variations between countries, as different lifetimes, discounts, and initial assumptions were selected for individual case-studies. In general, the cost of non-renewable resource depletion would be equal to the rent from resource extraction times a value *X* representing the discount factor in the final year of the resource selected lifetime. For individual countries, *X* takes the following values: Australia – 0.44; China – 0.80; India - 0.89. On the other hand, Talberth et al. (2006) use the replacement cost method to determine the value of depletion of non-renewable energy resources in the US, assuming that biomass is the only substitute, and applying a fixed price per barrel. Mineral resources are not accounted for in this study.

Similarly, in the studies from Lawn & Clarke (2008), both forests and fisheries depletions were calculated to reflect the opportunity cost of harvesting beyond the natural growth level. Similar to the case of non-renewable resources, El Serafy's user cost method was used and applied to the depleted resources (excess of natural growth). Hence, the value of depleted forest and fisheries was defined as rent from resource depletion (total extraction minus natural growth) times a value *X* (discount factor) that is the same as for non-renewable resources (see above paragraph). In the US, a very different approach is used, as the value is not only given by timber, but also by other lost ecosystem services. Furthermore, the US only accounts for loss of primary forests, along with damage from logging roads. Fisheries depletion is not accounted for.

The value of lost agricultural land calculated in some of the studies from Lawn & Clarke (2008) was determined as the amount required to compensate citizens for the cumulative impact of past and present agricultural practices. India assumes this value to represent 1% of the total agricultural output, while Australia weights the total agricultural area to the value of land degradation. On the other hand, for China and the US lost farmland, the cost of lost farmland was determined, by multiplying a fixed amenities and ecosystem services loss value per acre to the total area lost in the given year.

In GPI, CO2 damage was only determined for US. In their study, Talberth et al. (2006) adopted a value of $89.57 per metric tonne, in US dollars of the year 2000 (extracted from Tol (2005)).

GPI considers a broader list of items than ANS. The methodologies employed in calculating the other environmental items are not described in detail here, as those items are not accounted for in ANS, nor in the natural capital accounting systems assessed in this thesis. However, their value is included in the final results, as the plotted data represents the GPI lost natural capital services (the sum of all environmental costs). The types of environmental costs considered by GPI varies among different studies. Table 12 provides the types of items that are accounted for in the studies discussed in this thesis.

Table 12 GPI environmental cost items considered in the discussed studies

Item	Australia	China	India	Japan	USA
Non-renewable resource depletion	Yes	Yes	Yes	Yes	Yes
Lost agricultural land	Yes	Yes	Yes	Yes	Yes
Timber depletion	Yes	Yes	Yes	Yes	Yes
Air pollution	Yes	Yes	Yes	Yes	Yes
Urban waste-water pollution	Yes	Yes	Yes	Yes	Yes
Long-term environmental damage	Yes	Yes	Yes	Yes	No
Excessive irrigation water use	Yes	Yes	No	No	No
Fisheries depletion	Yes	No	No	No	No
Solid waste pollution	Yes	No	No	No	No
Lost wetlands, mangroves, and saltmarshes	Yes	No	No	No	Yes
Noise pollution	No	No	No	No	Yes
Ozone depletion	No	No	No	No	Yes
Carbon dioxide emissions damage	No	No	No	No	Yes

6.2 Results

Figure 2 below shows, on the left side, the bar charts of the natural capital accounting systems, IWI, CWI, and SEEA-AU for the years 1995, 2000, and 2005. On the right side of Figure 2, the environmental costs as determined by ANS and GPI are presented for every year over the period 1995-2005. For India and Japan, GPI data was only available until 2003, while for the United States, until 2004. The bar charts in Figure 2 were constructed using the same data as in the previous chapters. The GPI data on lost natural capital services was extracted from Lawn & Clarke (2008) for Australia, China, India, and Japan, and from Talberth et al. (2006) for US. The ANS data was extracted from the World Bank database (data.worldbank.org), as composed of the following indicators:

- Adjusted savings: energy depletion (current US$)
- Adjusted savings: mineral depletion (current US$)
- Adjusted savings: net forest depletion (current US$)
- Adjusted savings: carbon damage (current US$)
- Adjusted savings: particulate emissions damage (current US$)

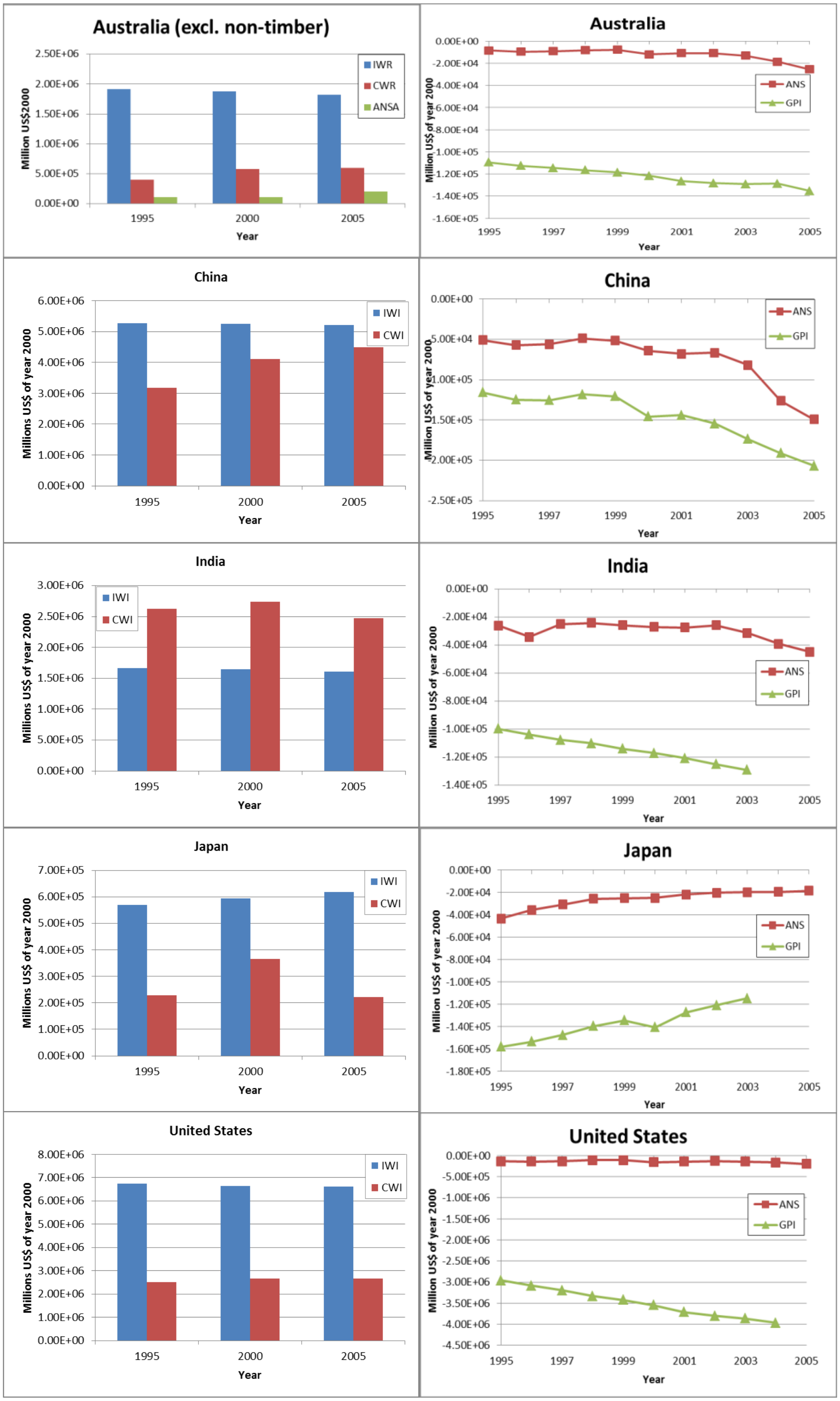

Figure 2 Natural capital accounting valuation of IWI and CWI and the cost of lost environmental assets as determined by ANS and GPI

Chapter 7. Discussion

7.1. Natural Capital Accounting Frameworks

The first research question, "*What are the differences in valuation approaches of the selected natural capital accounting frameworks (IWI, CWI, SEEA)?*", was approached from two different perspectives: methodological and numerical. Firstly, the discussion will concern the findings related to use of methodologies in the three natural accounting systems (as presented in Chapter 4.2). Secondly, the impact of using different data sources across the accounting systems will be discussed by referring to the results on individual natural capital assets of the four countries selected as case studies in Chapter 4.3.

7.1.1 Methodological approaches

No correlation between the estimates of IWI and CWI can be found for the 19 countries plotted in Annex 1. In some cases, IWI provides higher natural capital values (e.g. Australia and Canada), while in other cases, CWI shows higher values (e.g. Kenya and United Kingdom). Such differences can, in more extreme cases, approach one order of magnitude (see the case of Germany). Values for the selected years appear to be changing linearly and by small amounts as determined by IWI. However, there is no yearly correlation between the values provided by CWI, while changes can be very high during the chosen periods (France and Ecuador are good examples). Simply by looking at the data presented in Annex 1, it is not possible to deduct information about the accounting approaches, for instance, whether one accounting system or the other tends to provide higher or lower values.

From Table 2 (section 4.2) it can be observed that SEEA appears to have a more complete account of the natural capital assets. However, it is important to note that the CWI and IWI accounting frameworks were created with the aim to provide direct results for numerous countries. For this reason, the two systems were largely limited by data availability and not all natural capital assets could be included (e.g. water or biodiversity). On the other hand, SEEA only provides guidelines on how to account for the natural capital of one country, and advice regarding data required to do so. It does not provide country accounts itself, and hence, had more freedom to include a large number of natural capital assets.

In terms of methodology, net present value (NPV) can be used as an umbrella method, as it was found to be adopted by all accounting systems for most of the natural capital assets (see section 4.2). In this case, the differences in terms of the methodologies used by the accounting systems come from the initial assumptions regarding the asset lifetime, discount rate, rental rate, price, and extraction/production. Nonetheless, the net present value method was shown to be highly problematic due to a lack of optimisation framework. In most cases, total rents are assumed to remain constant over time, with constant production and unit rents. For an improvement of this method, the use of forecasted extraction paths and future rent projections is desirable. For instance, CWI employs a production growth rate for agricultural products (cropland and pasturelands) to account for the expected yield increase due to technological development and other factors. However, special care is required, as the predictions are not always correct. Although SEEA-UK uses forecasted extraction and income paths for their gas and oil resources, it was shown that these forecasts were not highly accurate (Office for Budget Responsibility, 2014).

Although NPV method is broadly used amongst the discussed accounting frameworks, differences in final results are expected even when the total rents are identical. For instance, the discount rate will create a difference, as some countries value the present higher (higher discount rate) than others. Hence, the methods employing a lower discount rate are expected to provide higher present values (assuming that the rents are identical). However, given the high uncertainty of the future resource rents and extraction paths, valuation cannot be confidently calculated for very long periods. The discount rate also influences the asset lifetime selected. In the case of IWI, the use of an infinite lifetime seems unnecessary. For periods further into the future than 20 years, NPV becomes relatively stable, as the increments are very small (less than 38% of the annual resource rent is added up for a discount rate of 5% in year 20). Of course, this varies depending on the discount rate. For instance, a declining discount rate could lead to significant increments after 20 years, which could lead to underestimations in the SEEA-UK calculations. For the other accounting systems, the asset lifetimes have reasonable values.

For timber, mineral, and energy resources, IWI uses a stock method, estimating asset value as the current price multiplied by the total stock. This method can be approached in two different ways. Firstly, the stock method can be treated as a special case of the NPV approach in which the lifetime is equal to 1 year, and the extraction is equal to the total stock in the current year. Secondly, it can be seen as an application of the Total Hotelling Rent (THR), in the form of the 'net price' depreciation (see Chapter 2), which assumes a price increase equal to the discount rate, until the stock is finished. However, as discussed in Chapter 2 (Theoretical Framework), this situation is highly unlikely as it requires a perfectly competitive market. Even when approached as a special case of NPV, the stock method is unrealistic as countries are not likely to extract all resources in one year, while the costs would increase with the depth of extraction (part of the reserves are more challenging to reach and to extract). It is important to note that the stock method used by IWI will produce significantly higher values than NPV and that it can be a major source of discrepancies in total wealth, as provided by the different accounting frameworks, for timber and soil resources rich countries.

New discoveries can have a high impact on the final result when sustainability over a given period is to be determined. An increase in wealth due to new discoveries can misleadingly indicate a case of sustainable development. The net present value is only affected by new discoveries through an increase in the lifetime of the reserve. However, considering that CWI, IWI, and SEEA-UK (only partially) use fixed or very long (infinite) lifetimes, new discoveries only have an impact when an asset that was not previously exploited is discovered and it is introduced in the wealth accounts. On the other hand, new discoveries can lead to significant wealth fluctuations in the case of gas and oil in SEEA-UK and all energy and mineral resources with short lifetime (e.g. Diamond) in SEEA-AU, as the assets lifetimes were calculated based on stocks and extraction paths. Although new discoveries would be expected to have a much higher impact on the stock method rather than on the NPV method, IWI tackled this problem by setting a fixed stock at the level of the most recent year, 2008. Hence, new discoveries would not influence the results over the given period (up to 2008). In the case of renewable resources, natural growth can take the place of new discoveries. However, natural growth is an important indicator of sustainability, as it shows good management of the resource. Hence, its impact on wealth over time is relevant.

All accounting frameworks discussed in this study (CWI, IWI, SEEA) used average costs and prices (deriving rents as the operating surplus of extracting companies) due to insufficient data to determine shadow prices, hence, ignoring consumer surplus, non-market values, and externalities. Using average costs rather than marginal costs would in most cases lead to an overestimate of the rental rate, as average costs are likely to be lower than marginal costs. Average rents are determined over a period of 5 years by CWI, SEEA-UK and SEEA-AU, while IWI averages over the entire 19-year period. Given the long time-period, IWI measures changes in wealth as a result of physical changes in the assets, ignoring the unit market value of each year. This can be a good approach in reducing price fluctuations. However, changes in price can be highly important in the long run, and averaging over long periods may hide potentially important market trends.

In what concerns timber resources, SEEA-UK is the only accounting framework that includes all forest resources in the calculations, and not only those that are commercially available. The limitation to commercially available forest (only 50km from infrastructure) might not be appropriate given the long, 25 year timeframes. If certain areas are deforested, infrastructure can be built to reach the newly uncovered areas. Using a lifetime to depletion when production exceeds natural growth makes the approach used in the CWI appear more realistic, but it does not take into account that finishing the commercially available resources might lead to further development and timber extraction (in areas not available in the year of valuation). No account is taken of the possibility of natural catastrophes or other sources of forest degradation in any of the accounting frameworks.

With regards to animal product valuation, IWI uses the method with the highest potential for error, pastureland value being determined as the average crop value times pastureland area (no animal products being considered). On the other hand, SEEA-AU is likely to produce the most accurate results due to its approach in valuing animal products more directly and not the land that they use (i.e. pastureland). This also allowed for the use of the age-efficiency function which could help predict future changes in production. Furthermore, SEEA-AU includes more animal products than CWI and IWI (only wool, meat, and milk), such as egg laying hens, pets, honey, eggs, and the agistment service value.

7.1.2 Case studies – methodology versus data

Chapter 4.3 presents the values of natural capital accounting assets for four individual countries: Australia, Brazil, South Africa and the United Kingfom. Data analysed along with these values include indicators such as unit prices, production, extraction, surface areas, rental rates and others. In the following discussion, the results will be analyzed to determine the impact of methodology as well as of data differences in the final values. The natural capital accounting assets discussed are: energy and mineral resources, forest resources, and agricultural resources.

Energy and mineral resources

In terms of fossil fuels, IWI provides the highest monetary values for all countries, except the UK. This occurs as a result of methodology used (stock method rather than NPV approach), but also due to the reserve baseline level being set in the year 2008. When analyzing the reserves used by SEEA-AU, SEEA-UK and CWI, it is in most cases found that these reserves increase over the years, unlike in the case of IWI. This is due SEEA and CWI sensitivity to new discoveries and, potentially, also due to technological developments that make extraction possible. It is also important to note that while IWI and CWI use proved reserves, SEEA-AU and SEEA-UK use both proved and probable reserves. The annual production levels are similar across accounting frameworks for most countries and should not be a significant source of value differences. This is also the case for prices which, although different across the accounting systems, are found within the same order of magnitude. The major differences are rather determined by the approaches in determining stocks and the accounting methodology used (NPV versus stock approach). The price used by IWI is the same for all 3 years, as it was determined as an average over the 19 year period.

It is important to note that although both CWI and IWI have used similar sources, the International Energy Statistics of the U.S. Energy Information Administration (CWI uses the British Petroleum data in addition), it is likely that significant updates have been made to these statistics between 2006 (when the data was retrieved for CWI), 2011 (when it was retrieved for IWI), and 2014, when it was collected for the current work. For instance, CWI finds zero wealth value for soft coal in Australia, and in year 2000, for both hard and soft coal. However, USEIA (2014) shows extraction, production, and consumption of coal during this period. The same is valid for oil in South Africa during the year 1995. In IWI, the value of coal appears to dominate the total value of fossil fuels, especially in Australia and South Africa, and less so in Brazil. However, the value provided by CWI is zero for Brazil, and up to 4 orders of magnitude lower that that provided by IWI for Australia and South Africa.

IWI and CWI used the same data for mineral resources (reserves and production), and therefore, the differences in the monetary values of this asset is expected to occur from the difference in methodologies only. Although it was expected that IWI will produce significantly higher values than CWI as a result of methodology, this is not visible in the final results. A lack of monetary valuation data for individual mineral assets by CWI does not allow for a more in-depth analysis of the results.

Valuable subsoil assets such as diamonds, lithium, uranium, and platinum are not included by IWI and CWI due to a lack of reliable data. Although SEEA-AU made available values for a few more minerals (e.g. diamond), these values were excluded from the calculation. The data used by SEEA-AU in terms of prices, annual production, and reserves, is similar (same order of magnitude) to that used by CWI and IWI. Hence, the monetary value differences are expected to sprout from the difference in methodology only.

In the case of UK, there was not sufficient overlap in terms of mineral resources between SEEA-UK and IWI and CWI to make a comparison of the values provided. For this reason, only energy resources were considered in this section for the UK.

Forest resources

In the case of forest resources, all accounting systems use different data sources for their valuation, with discrepancies in the numerical data of up to 100% (only in a few cases, the majority being characterized by a much lower percentage) of any given value.

Similar to the case of energy and mineral resource, if the same data would be used, IWI would be expected to provide the highest value, in most cases, due to its methodological approach (stock method). However, because timber is a renewable resource and stocks can replenish and increase over time, there are also situations in which NPV could provide a higher value. When verifying the results IWI provides the highest value for Australia, Brazil, and partially the UK, but not for South Africa. However, for South Africa, IWI provides identical monetary values over the 19 years for both timber (6901 million US$ of the year 2000) and non-timber resources (2255 million US$ of the year 2000). These values cannot be the result of applying the IWI methodology. Different values are expected every year, considering the change in forest area, wood production, as well as prices (although IWI uses an average price). For this reason, South Africa will not be discussed in this section.

In the case of Australia, the values provided by IWI slightly increase in the year 2000, and decrease back down in 2005. Similar changes can be observed in CWI, although more dramatic, fluctuating by up to 40000 million US$ rather than just 1000 million US$ (in the case of IWI). This cannot be explained by changes in wood production, nor in prices, as both increase over the given period. The data used by IWI shows a slight decrease followed by an increase in forest area, which would be expected to impact on the final monetary values in the same direction, as opposed to the observed situation (increase, followed by a decrease). SEEA-AU shows a decrease in value, followed by an increase. However, unavailability of data used by this accounting system does not allow for comparison. Brazil and UK, similarly, show values that are difficult to explain by means of the available data. The reason may be that the data retrieved from the indicated sources for the purpose of this study may not be the exact data used by the accounting systems.

Agricultural Assets

From data retrieved in this study, the cropland area used by IWI appears to be 1-2 orders of magnitude lower than that used by CWI. This difference in area could explain the asset values up to 10 times higher in the case of CWI as compared to IWI. Areas used for pastureland valuation are identical for the two accounting systems. However, the valuation methodology dictates the major differences (i.e. NPV assumptions, and used rental rates).

Data for Australia was not introduced in Table 11 because it was not possible to separate livestock value from plant resources. Although data on livestock values exist, this could not be used to determine the plant value through extraction from the total cultivated biological resources. The value of livestock is close to the total value of cultivated biological resources, and sometimes exceeds it. For instance, for the year 1995, the livestock value is 12522 million AUD at current prices, while the total value of cultivated biological resources of the same year is 11900 million AUD at current prices as closing stocks. The closing balance sheet values of cultivated natural resources as given by the ASNA are 9960.74, 9093.54, and 13242.44 million US$ of the year 2000, for the years 1995, 2000, and 2005 respectively. These values are 2 orders of magnitude lower than those provided by IWI and CWI.

Similarly to Australia, agricultural assets value as provided by SEEA-UK was not included in Table 11 because it could not be separated into cropland and pastureland values. The total value of agricultural assets in year 2007 was 54861 million US$ of the year 2000. This value is lower than the expected result of IWI, but higher than that expected from CWI (if cropland and pastureland would be summed up as agricultural assets).

7.2 Accounting for Non-market Values

This section of the discussion provides an answer to the second research question, "*Would the inclusion of non-marketed ecosystem services valuation lead to significant changes in the total natural capital value determined by the natural capital accounting frameworks (IWI, CWI, SEEA)?*", by analysing the findings in Chapter 5. The countries selected as case studies for this section of the research were also Australia, Brazil, South Africa, and United Kingdom. The TEEB database was used to obtain an understanding of the scale of non-marketed ecosystem services value, as compared to natural capital valuation.

As shown in Chapter 4, IWI and CWI only account for 4 energy resources and 10 major metals. However, valuable subsoil assets such as diamonds, lithium, uranium, and platinum are not included due to a lack of reliable data. Although SEEA-AU provides a longer list of minerals, there are still limitations. Furthermore, fisheries have only been included by IWI (only for four countries) due to lack of information concerning fish stocks and future changes. Water is not analysed as an individual asset either, by CWI nor IWI, although SEEA-AU/UK determine a value for it. Although some water related benefits are included in the value of other assets, such as agricultural land, others, such as hydropower, are ignored. These are only some of the provisioning ecosystem services that are not included in the natural capital accounting systems discussed in this thesis. However, what is most often completely ignored are the regulating and cultural services. Public goods such as carbon storage and biodiversity are missing from the accounts. The value of protected areas is largely underestimated or unaccounted for, although people are willing to pay significant amounts to visit such places, to live in areas of natural beauty, or simply to know that they continue to exist.

For CWI, any values of natural capital that are not determined individually in the natural capital accounts are assumed to be included in the intangible capital. These can include some mineral (diamonds, platinum), fisheries, groundwater, etc. However, the intangible capital would only encompass those benefits that are directly or indirectly marketed. Values of intermediate ecosystem services such as the benefits of forests in terms of pollinators and the maintenance of the watershed that have an impact on agriculture are included in the value of croplands. Nonetheless, numerous other ecosystem services, such as the enjoyment of a walk into the forest or of snorkelling among coral reefs are not included.

CWI and IWI are the only accounting frameworks that include a non-timber value of forests (SEEA-EEA also allows for this inclusion, but is not considered in SEEA-AU/UK). Both of them use fixed values and a10% accessibility to the forest and its ecosystem services. The difference between the two accounting frameworks methodologies comes from general characteristics, such as discount rate, selected timeframe, and non-timber value per hectare. Nonetheless, this thesis argues that only accounting for 10% of the forest area ignores important indirect-use forest value such as weather regulation, water regulation, and the existence and bequest value of biodiversity.

UNU-IHDP and UNEP (2012) argue that shadow prices would be able to solve the issue of non-marketed ecosystem services, as shadow prices would reflect the value of these services flowing from an asset. However, a good methodology for the measurement of shadow prices is still to be developed, and it will not be possible without a good understanding of ecosystem services and their valuation. Another issue that is often encountered is that of double counting. It is often difficult to separate, for instance, the forest value of flood regulation from the current value of housing or agricultural assets in the flood prone area (if the flood regulation ecosystem service would not exist, then these assets would not exist either, or would have a lower value).

The importance of ecosystem services that are not accounted for is strongly emphasized by SEEA-UK in its valuation of outdoor recreational value. As shown by ONS (2014), this value is approximately 6.4 times larger than the total value of mineral, energy, timber, agricultural land, and water resources added together. This chapter obtained an understanding of excluded ecosystem services by adding up the values from the TEEB database. However, it is very important to note that these values represent only specific ecosystem services of individual ecosystems across countries, and that they are not scaled up to a national level. It is expected that a complete account of all country-level ecosystems and their services would bust this value significantly.

In the case of Australia, the value of ecosystem services determined from the TEEB database are up to two orders of magnitude higher than the value of natural capital provided by the accounting systems. However, this value fades away and becomes one order of magnitude lower in comparison when the coastal valuation provided by Blackwell (2006) is excluded. The value provided by Blackwell (2006) is significantly larger than all other ecosystem valuations for Australia, although it is important to note also that it covers the largest ecosystem (all surrounding coast of Australia). Given the large size covered, this value may be realistic. Nonetheless, it is most likely not entirely accurate given the valuation method used (explained in chapter 5.2) - some coastal regions may have a lower value than others due to lack of accessibility and difference in resources.

Similar to the findings of ONS (2014) on recreational value as compared to natural capital, this study shows the enormous economic potential of ecosystem services in the United Kingdom. Although in this situation the dominant ecosystem services in terms of value are carbon sequestration and nutrient cycle, followed by recreation, the TEEB-determined value is 10 to 22 times higher than the value of natural capital provided by the accounting systems.

Brazil's TEEB-determined ecosystem services also show a higher value (sometimes twice as high) than the natural capital value provided by CWI and IWI. This is not the case for South Africa, which is the only country, out of the four, with a lower value for TEEB-determined ecosystem services than that given by the accounting systems (only approximately 50% of the accounting system value). Nonetheless, this might be a result of less research being conducted in this country.

Although non-timber forest resources are included in Brazil's and South Africa's natural capital accounting, the overlap with the value determined from ecosystem services is not expected to make a significant difference (or to be able to explain the results). For Brazil, non-timber forest resources represent less than 10% of the total natural capital accounting value (including all assets), while for South Africa, less than 0.7%.

In this analysis approach, some concerns remain with respect to double counting, a situation that occurs when the ecosystem services valued independently are also present in the natural capital accounts, hidden in the built-up of resource rents. For instance, the values of soil fertility and pollination are also encompassed (perhaps not fully) in the value of crops, as determined by the natural capital accounting systems.

This study assumed that the valuation methods used in the study extracted from TEEB database would be additional to the natural capital accounting frameworks. However, an appropriate integration of ecosystem services into natural capital accounting would require the consideration of a number of aspects. For instance, Obst et al. 2015 argue that the aggregation of non-market ecosystem services valuation and SEEA would demand the use of exchange values for consistency purposes. In line with this reasoning, they suggest that appropriate valuation methods for non-market ecosystem services are resource rents (residual after all forms of capital have been deducted from the operating surplus), production/cost function (relating outputs of marketed goods and inputs of ecosystem services), marginal values from revealed demand functions, replacement cost, and hedonic pricing. All valuation methods that include consumer surplus (e.g. preference methods), as well as the use of restoration costs are considered inappropriate.

7.3 Loss and Degradation of Natural Capital

To answer the last research question, "*Are there numerical or methodological correlations between natural capital value changes and environmental costs (lost natural capital and externalities) determined over a given period of time?*" ANS and GPI were used as indicators of the cost of lost ecosystem services and environmental degradation. The numerical and graphical results in Chapter 6 are analysed below.

The cost of lost natural capital services, as shown by both ANS and GPI, has increased over the period 1995-2005 for all countries analyzed, except Japan, where this cost has decreased. Similarly, IWI shows a decrease in natural capital for all countries over the studied period except for Japan, where the natural capital value increased. On the other hand, CWI shows an increase in natural capital accounting value for Australia, China and the US, but an increase, followed by a decrease, for India and Japan. SEEA-AU shows an increase in the natural capital value in Australia. This section will proceed by performing a more detailed analysis of what drives the results presented in chapter 6.2, first by looking at the data for each country, and secondly by considering the methodology used by each valuation system.

ANS for **Australia** is dominated by non-renewable resources depletion and carbon dioxide damage which all increase over time. The GPI information provided in Lawn & Clarke (2008) for individual environmental cost items in Australia was insufficient to explain the results. The IWI value decrease in Australia is given by physical stock decreases.

On the other hand, the situation for CWI is more complex. Although cropland and pastureland increase significantly in 2000 and decrease again in the final year, this is overtaken by a very strong increase in fossil fuel and mineral resources value in the final year. This abrupt change is also visible in the final years of ANS.

In **China**, the shape of the ANS plot is dominated by the changes in energy depletion and carbon damage. There was insufficient information in Lawn & Clarke (2008) to explain the GPI results. The correlation between ANS and GPI is clear in Figure 2. However, the costs increase shown by ANS and GPI in the years 1998-1999 cannot be compared to changes in values provided by IWI, nor CWI, due to results being shown only in 1995 and 2000 (as CWI only reports every 5 years). The values in CWI are driven by cropland and subsoil assets, while in IWI by fossil fuels.

ANS for **India** has no dominant item until the last two years when an abrupt increase in energy depletion and carbon dioxide damage drives the sudden cost increase observed in the plot in Figure 2. The available data was insufficient to determine what drives the steady environmental cost increase in GPI. In IWI, fossil fuels and agricultural assets are the main items that lead to the observed changes, while in CWI, agricultural resources is the dominant item that leads to an increase in natural capital value in the year 2000, followed by a decrease in 2005.

The increase in the natural capital value in **Japan** as shown by IWI was determined by an increase in forest resources. On the other hand, the ANS value is dominated by the particulate matter damage which strongly decreases over the given period. ANS does not have any values for the forests in Japan. The GPI value is dominated by the cost of water pollution which shows a strong decrease down to 15% of the initial value over time. Air pollution is also contributing to the decrease of the total GPI value. CWI is dominated by the value of pastureland, which has the highest value among the assets doubles in the middle year and then decreases back to its initial value.

The ANS data for the **United States** is dominated by particulate matter, energy depletion and carbon damage. There are irregular variations in the costs of these items and they often cancel one another, also leading to irregular variations in the total ANS value. GPI is driven by resource depletion which is steadily increasing. The results from IWI reflect the decrease in fossil fuel resources. There is no dominant item in CWI that can explain the slight increase in natural capital value over time. There are irregular variations in the individual assets considered by this accounting system that cumulate or cancel out.

No correlation is expected between IWI and ANS or GPI, as IWI uses a stocks approach, where the price is constant and the changes in capital value is driven by the changes in physical stocks. On the other hand, the values in ANS and GPI are driven by annual production/depletion and are sensitive to price/rents fluctuations. If ANS used a fixed price over the given period, its value for non-renewable resources depletion would have represented the changes in natural capital value for those resources from one year to another. A clear inverse correlation for the common items of ANS, GPI and CWI is expected for non-renewable resources, given comparable data use. As non-renewable resources and timber value is determined using the NPV approach, a higher production or a higher price, will lead to a higher natural capital value (assuming that lifetime does not shorten). On the other hand, a higher production and price, would lead to a higher cost of depletion in ANS and a higher opportunity/replacement cost in GPI (assuming that natural forest growth changes do not take over production changes). Nonetheless, the overall value of each indicator can be dominated by additional items and the expected correlation can be broken (example of particulate matter in Japan), which was found in this chapter's case studies as well.

It is important to note that the costs provided by ANS are generally a few orders of magnitude lower than the natural capital accounting values. However, GPI provides values that are comparable (same order of magnitude or one order lower) to the natural capital accounting values. Although mineral and energy resources often account for a substantial part of the ANS and GPI values, the other items that build-up these indicators (e.g. particulate matter pollution, carbon dioxide pollution, etc) are often dominating. This shows that there are important externalities linked to economic activities that affect natural capital and its ecosystem services. The impacts of some of these externalities are expected to be apparent in national accounting of human capital (e.g. health impacts of particulate matter) and in measurements of ecosystem services flow (decrease due to ecosystem degradation).

7.4 Problems and limitations

One important limitation of this research was data availability. As shown earlier, data was only available for a small sample of countries, and mostly for those pertaining to the upper middle income and the high income groups. Nonetheless, this sampling limitation is not expected to have a great impact on the final conclusions and generalisations. Greater attention will be directed toward the accounting methodology, while the country based natural capital values will only serve as examples, and not as generalisation tools. Furthermore, answering the second research question was very challenging due to lack of complete data. TEEB only provides ecosystem services valuation for a few ecosystems in each country, and does not cover the entire area and spectrum of ecosystem services. Additionally, values are determined in distinct studies, employing distinct methodologies and hence, leading to inconsistencies in valuation. Moreover, it is difficult to verify each methodology used and to determine limitations and possible flaws. Answering the last research question was confronted with a lack of detailed information on the individual GPI items for some of the countries (e.g. China). For this reason, where data was not available, it was not possible to determine what items were dominant in shaping the changes observed in the indicator over time.

Chapter 8. Conclusion

A comparative analysis of the three natural capital accounting systems (IWI, CWI, SEEA) performed in this study showed that, in general, SEEA-CF is the most complete accounting framework, covering a broad range of assets. However, SEEA-CF was only constructed to provide guidelines on the calculations, and does not apply existing data itself, as IWI and CWI do.

Analysis of selected natural capital frameworks on methodological approaches noted that CWI and SEEA rely entirely on the NPV approach in valuing the considered natural capital assets. IWI also uses this method in determining the value of crops, pasturelands and non-timber forest benefits. However, each accounting system uses a different selection of discount rates, lifetime extents, and resource rents, leading to significant variations in the expected natural capital values. For the valuation of mineral, energy, and timber resources, IWI uses a stocks approach, determining the value of the entire stock, given the current unit value, rather than the flow of benefits (resource rents) over a pre-defined period of time in the future (as NPV does). This value would generally (with possible exceptions in the case of timber) be significantly higher than the values determined with the NPV method, assuming that the same price and stock data is used. Both NPV and the stock method have advantages and disadvantages. Choosing one method over the other depends on what needs to be measured (whether the change in natural capital or the fluctuation in prices and extraction) and on the importance that is given to the present moment with respect to future years (extract all in the present, or consider future discounted flows).

In-depth analysis of four countries data (Australia, Brazil, South Africa and UK) suggested that the differences in values provided by the individual accounting systems do not arise from the use of distinct methodologies alone, but also from the use of a diverse range of data resources. It was found that there are often significant differences in the data used by the three accounting systems, sometimes leading to different outcomes than those expected from methodological approaches. However, limitations were encountered while conducting this part of the research, due to unavailability of data used by the accounting systems or to insufficient information in the main natural capital accounting systems reports.

This study provided a scale to the expected changes in the value of natural capital accounting if non-marketed ecosystem services, as determined in the studies available in TEEB database, would be included. It is important to note that there are a number of limitations to this study. Firstly, there is insufficient data to cover all ecosystem services at a national level. Secondly, the used data is extracted from individual studies that use different methodologies and therefore, significant inconsistencies may arise. If ecosystem services were to be included in the national accounting systems, clear guidelines on methodology would need to be outlined. Nonetheless, despite the limitations imposed by data availability, this chapter clearly shows the incontestable importance of non-marketed ecosystem services. Even if taking into account potential overlap in data, the TEEB-determined values would still be comparable (same order of magnitude or one order lower/higher) or much higher than the values determined by the accounting systems. South Africa was the only country (out of four) in this study to show a lower non-marketed ecosystem services value than the natural capital accounting systems. However, this may be the result of lack of sufficient research (available studies in TEEB database), leading to a low number of ecosystem services included in the valuation. Perhaps the most important message of this chapter is that, although non-marketed ecosystem services were shown to hide a huge monetary value, including all ecosystems and their provided services from each country would significantly boost the values presented in this study.

Finally, the magnitude of environmental cost from lost natural capital and externalities linked to economic activities (as determined by ANS and GPI), in comparison to the natural capital accounting changes over time was assessed. It was found that there are no clear correlations between the natural capital accounting values (IWI, CWI, SEEA-AU/US) and the values provided by ANS and GPI. Although graphical representation of the indicators might show correlation, it was observed that the shape of the ANS and GPI plots were in most cases driven by other items than those that dominated natural capital accounting valuation. Given the methodology employed for each item, a clear correlation is expected between mineral, energy and forest resources of CWI, and those of ANS and GPI. The comparable (0 to 2 orders of magnitude lower) values of ANS and GPI to the values of the natural capital accounting systems suggest that there are high environmental costs generated as externalities of economic activities (e.g. CO2 or particulate matter damage).

Although natural capital accounting has come a long way across, there are still significant limitations that need to be addressed. Further research needs to be conducted towards fully integrating non-marketed ecosystem services into natural capital accounting framework, and towards ensuring the integration of environmental damage and externalities that do not currently appear in the accounting frameworks (pollution impact on environmental and human productivity). Moreover, given the current limitations, future studies should also strive to improve current methodologies to better reflect reality (e.g. through use of forecasted price and production changes, or developing methods to determine shadow prices).

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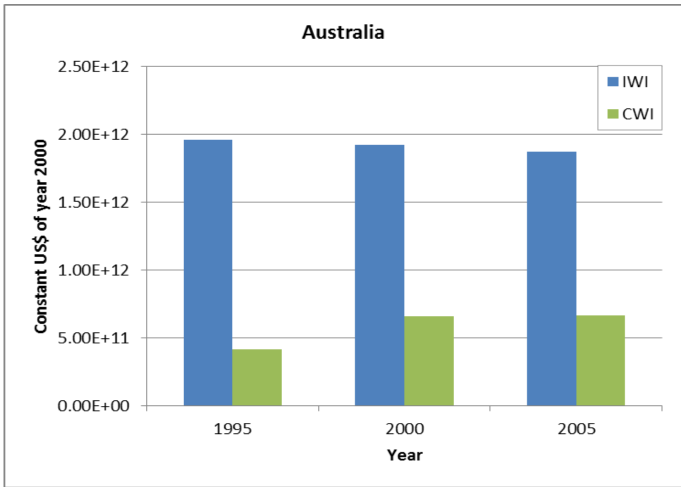
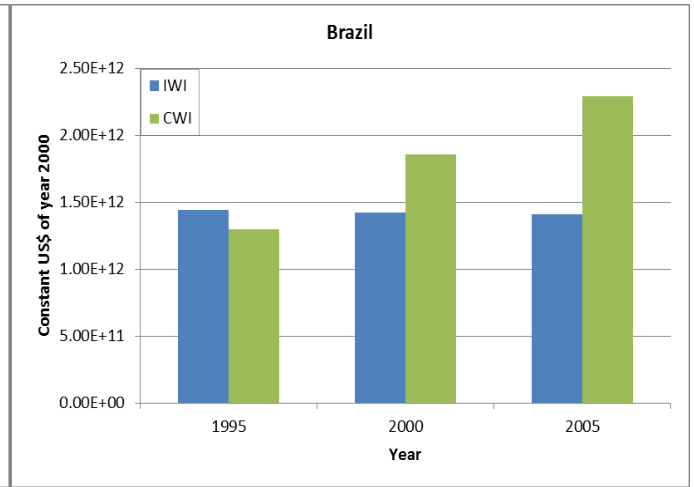
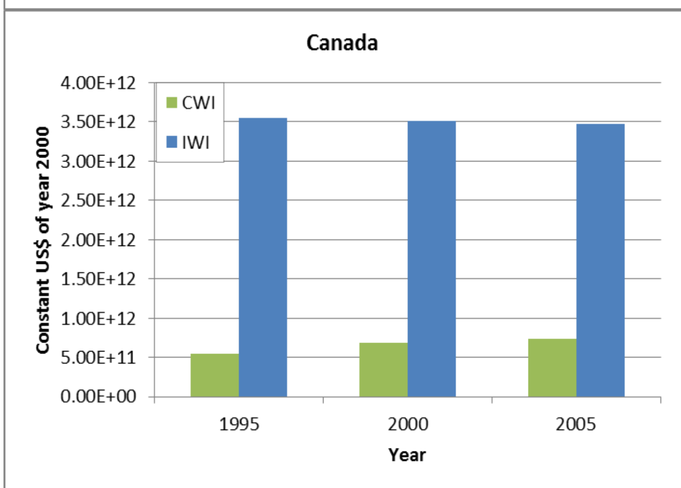
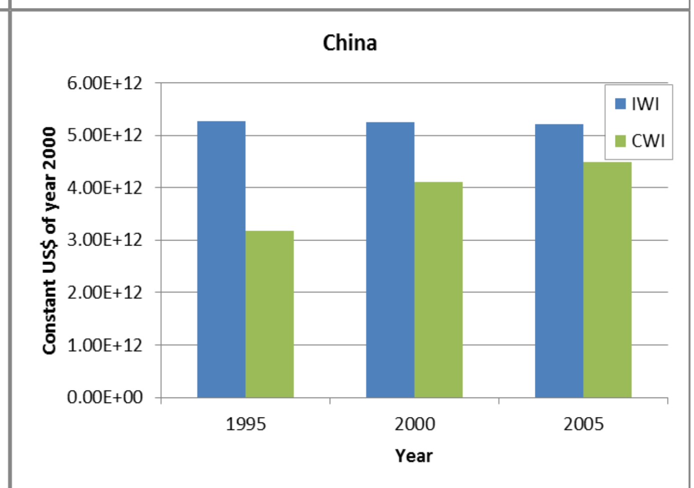
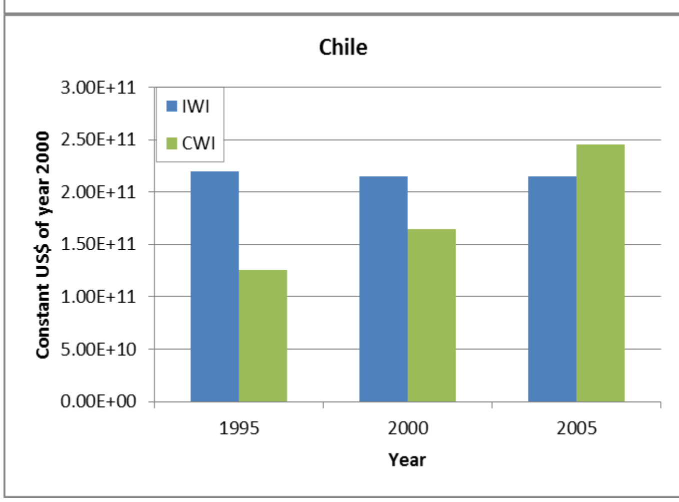
Annex 1 Inclusive Wealth Index (IWI) & Comprehensive Wealth Index (CWI)

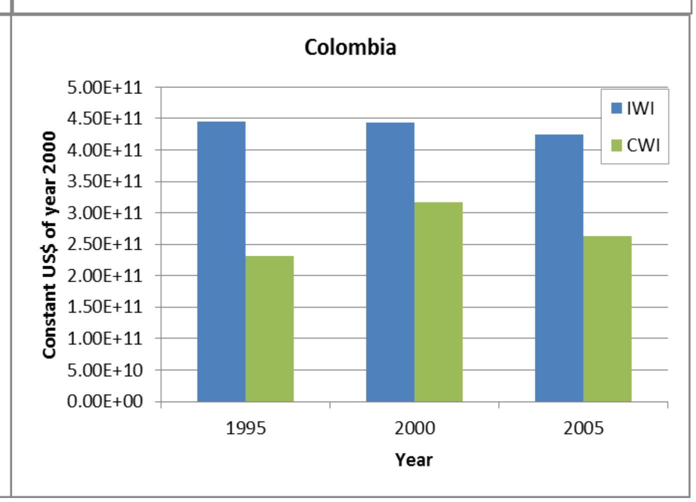


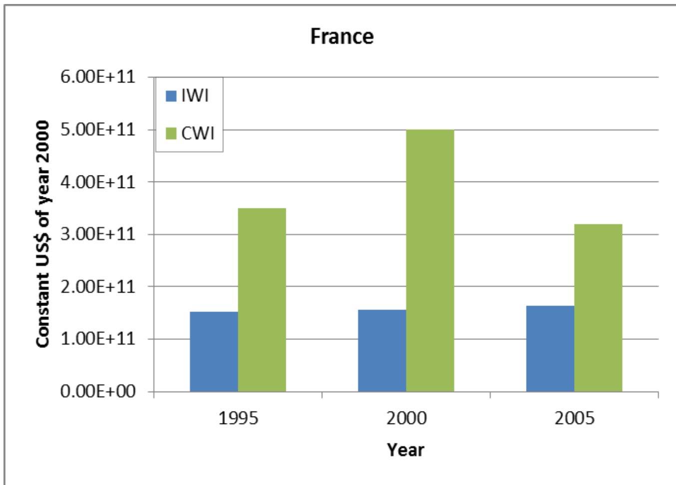


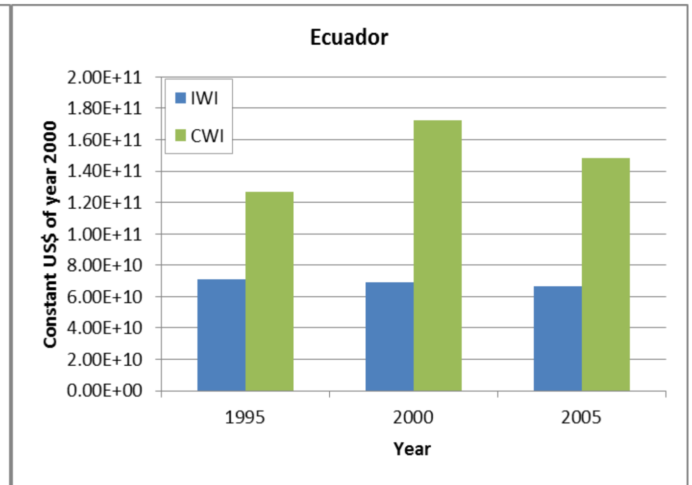


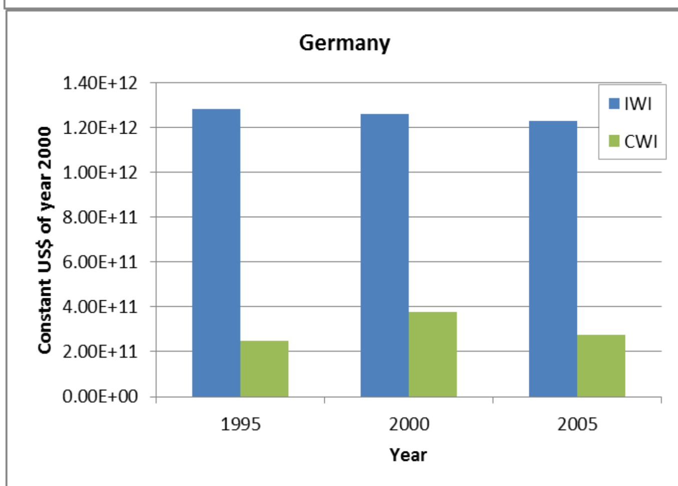


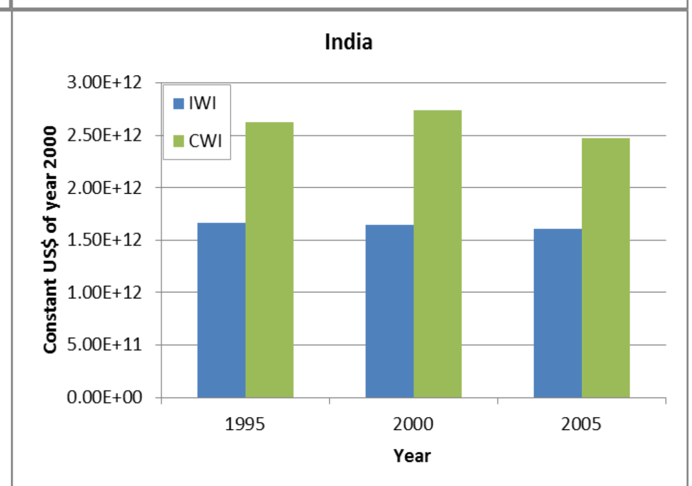


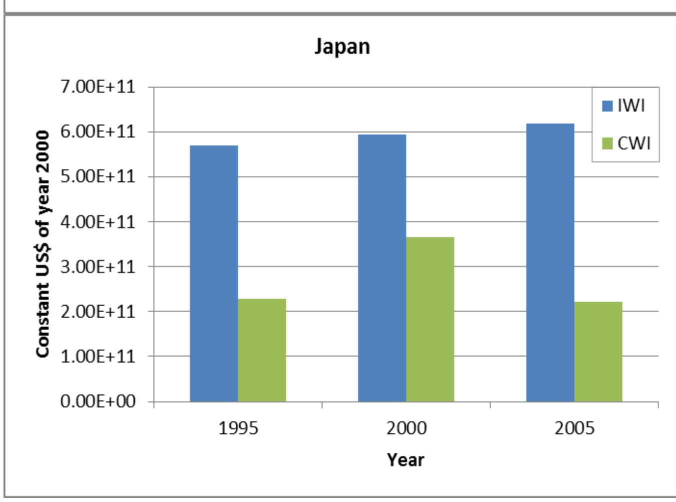


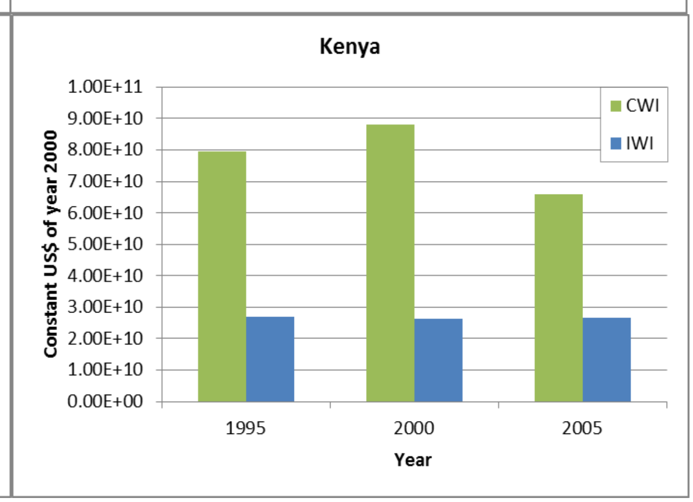

France
IWI
CWI
Constant US$ of year 2000
6.00E+11
5.00E+11
4.00E+11
3.00E+11
2.00E+11
1.00E+11
0.00E+00
1995
2000
2005
Year

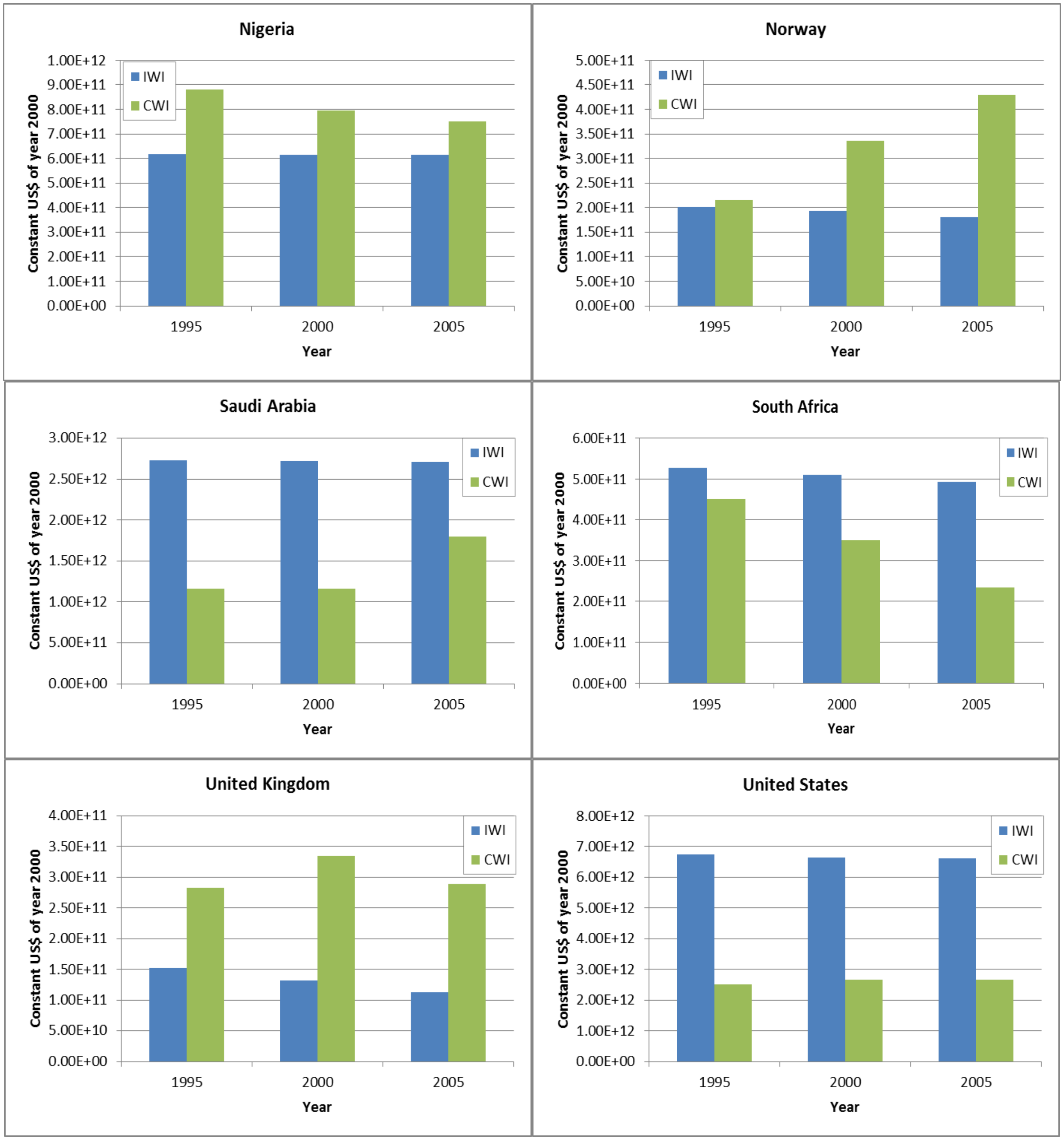

Ecuador
IWI
CWI
Constant US$ of year 2000
2.00E+11
1.80E+11
1.60E+11
1.40E+11
1.20E+11
1.00E+11
8.00E+10
6.00E+10
4.00E+10
2.00E+10
0.00E+00
1995
2000
2005
Year

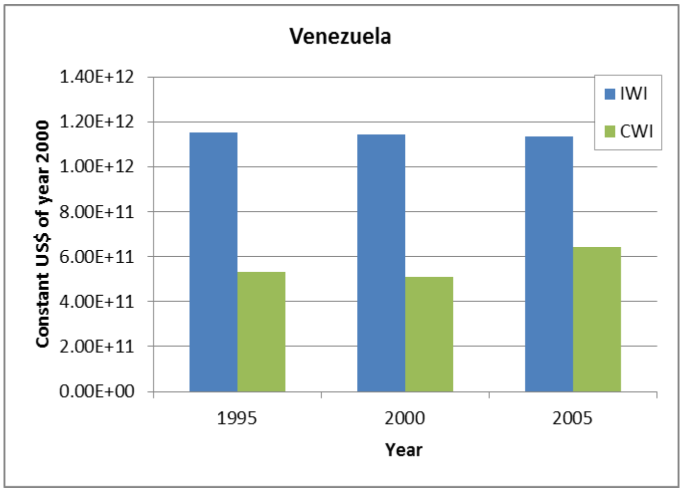

Germany
IWI
CWI
Constant US$ of year 2000
1.40E+12
1.20E+12
1.00E+12
8.00E+11
6.00E+11
4.00E+11
2.00E+11
0.00E+00
1995
2000
2005
Year


India
IWI
CWI
Constant US$ of year 2000
3.00E+12
2.50E+12
2.00E+12
1.50E+12
1.00E+12
5.00E+11
0.00E+00
1995
2000
2005
Year


Japan
IWI
CWI
Constant US$ of year 2000
7.00E+11
6.00E+11
5.00E+11
4.00E+11
3.00E+11
2.00E+11
1.00E+11
0.00E+00
1995
2000
2005
Year


Kenya
CWI
IWI
Constant US$ of year 2000
1.00E+11
9.00E+10
8.00E+10
7.00E+10
6.00E+10
5.00E+10
4.00E+10
3.00E+10
2.00E+10
1.00E+10
0.00E+00
1995
2000
2005
Year


Nigeria
1.00E+12
9.00E+11
8.00E+11
7.00E+11
6.00E+11
5.00E+11
4.00E+11
3.00E+11
2.00E+11
1.00E+11
0.00E+00
IWI
CWI
Constant US$ of year 2000
1995
2000
2005
Year
Norway
5.00E+11
4.50E+11
4.00E+11
3.50E+11
3.00E+11
2.50E+11
2.00E+11
1.50E+11
1.00E+11
5.00E+10
0.00E+00
IWI
CWI
Constant US$ of year 2000
1995
2000
2005
Year
Saudi Arabia
3.00E+12
2.50E+12
2.00E+12
1.50E+12
1.00E+12
5.00E+11
0.00E+00
IWI
CWI
Constant US$ of year 2000
1995
2000
2005
Year
South Africa
6.00E+11
5.00E+11
4.00E+11
3.00E+11
2.00E+11
1.00E+11
0.00E+00
IWI
CWI
Constant US$ of year 2000
1995
2000
2005
Year
United Kingdom
4.00E+11
3.50E+11
3.00E+11
2.50E+11
2.00E+11
1.50E+11
1.00E+11
5.00E+10
0.00E+00
IWI
CWI
Constant US$ of year 2000
1995
2000
2005
Year
United States
8.00E+12
7.00E+12
6.00E+12
5.00E+12
4.00E+12
3.00E+12
2.00E+12
1.00E+12
0.00E+00
IWI
CWI
Constant US$ of year 2000
1995
2000
2005
Year


Venezuela
1.40E+12
1.20E+12
1.00E+12
8.00E+11
6.00E+11
4.00E+11
2.00E+11
0.00E+00
Constant US$ of year 2000
IWI
CWI
1995
2000
2005
Year

Annex 2 Data sources extracted from TEEB database

Australia – Selected data sources from TEEB database

Scientific Work	Ecosystem	Ecosystem Service	ESSubservice	Method
Perrot-Maître and Davis (2001)	Temperate forest	Waste	Water purification	PES (?)
Access Economics (2008)	Coral reefs	Food , Recreation	Fish, Tourism	Direct market pricing
	Aquaculture	Food	Fish	
Carl and Mendelsohn (2003)	Coral reef	Recreation	Tourism	Travel Cost
Curtis (2004)	Tropical forest	Food	Unspecified	Direct market pricing
		Genetic	Unspecified	
		Water	Unspecified	
		Air quality	Capturing fine dust	
		Climate	Gas regulation	
		Water flows	Water regulation	
		Erosion	Erosion prevention	
		Waste	Water purification	
		Waste BioControl	Soil detoxifiation	
			Unspecified	
		Extreme events	Prevention	
		Recreation	Recreation	
		Soil fertility	Soil formation	
		Soil fertility Pollination	Nutrient cycling	
			Unspecified	
		Nursery	Species refugia	
		Genepool	Biodiversity protection	
		Cultural services	Unspecified	
Blamey, Rolfe, Bennett and Morrison (2000)	Other woodlands	Genepool	Biodiversity protection	Contingent valuation
Rausser and Small (2000)	Mediterranean woodlands	Medical	Bioprospecting	Factor income/production
Gren and Soderqvist (1994)	Flood plains	Recreation TEV	Recreation TEV	Benefit transfer
Donaghy, Chambers, Layden (2007)	Flood plains	Genepool	Biodiversity protection	Benefit transfer
Blackwell (2006)	Marine	Unspecified	TEV	TEV
	Coastal	Estuaries	TEV	
		Seagrass/Algae	TEV	
		Continental Shelf Sea	TEV	
	Coastal wetlands	Mangroves	TEV	
	Coral reef	Coral reef	TEV	
Arthur and Boland (2006)	Coastal	Seagrass/algae beds	Nursery	Factor/income production

Brazil – Selected data sources from TEEB database

Scientific Work	Ecosystem	Ecosystem Service	ESSubservice	Method
Seidl and Moraes (2000)	Floodplains	Climate	Gas regulation	Benefit Transfer
		Climate	Climate regulation	
		Extreme events	Prevention	
		Water flows	Water regulation	
		Water	Unspecified	
		Erosion	Erosion prevention	
		Soil fertility	Soil formation	
		Soil fertility	Nutrient cycling	
		Waste	Waste treatment	
		Pollination	Unspecified	
		BioControl	Unspecified	
		Genepool	Biodiversity protection	
		Food	Unspecified	
		Raw materials	Unspecified	
		Genetic	Genetic resources	
		Recreation	Tourism	
		Inspiration	Cultural use	
Torras (2000)	Tropical forest	Extreme events	Flood prevention	Benefit Transfer
		Recreation	Recreation	
		Food	NTFPs	
		Genepool	Biodiversity protection	
		Climate	Climate regulation	
		Erosion	Prevention	
Verweij, Schouten, Van Beukering, Triana, Van der Leeuw and Hess (2009)	Tropical Forest	Extreme events	Fire prevention	Benefit transfer
		Genepool	|Biodiversity protection	
		Climate	C-sequestration	
		Erosion	Prevention	
Rauser and Small (2000)	Tropical Forest	Medical	Bioprospecting	Factor/income production
Muniz-Miret, Vamos, Hiraoka, Montagnini and Mendelsohn (1996)	Tropical forest	Food	NTFPs	Direct market pricing
Horton, Colarullo, Bateman and Peres (2003)	Tropical forest	Genepool	Biodiversity protection	Contingent valuation

South Africa – Selected data sources from TEEB database

Scientific Work	Ecosystem	Ecosystem Service	ESSubservice	Method
Adekola, Moradet, de Groot and Grelot (2008)	Swamps / marshes	Food	Plants / vegetable food	Direct market pricing
		Raw materials	Other Raw	
		Ornamental	Decorations / Handicrafts	
		Raw materials	Fuel wood and charcoal	
		Food	Meat	
		Food	Fish	
Turpie, Heydenrych and Lamberth (2003)	Coastal [unspecified]	Food	Unspecified	Direct market pricing
	Coastal [unspecified]	Genepool	Biodiversity protection	Contingent Valuation
	Multiple ecosystems	Recreation	Tourism	Direct market pricing
	Tropical forest	Raw materials	Unspecified	Direct market pricing
	Tropical dry forests	Food	Unspecified	Direct market pricing
	Tropical dry forests	Genepool	Biodiversity protection	Contingent Valuation
	Tropical dry forests	Food	NTFPs [food only!]	Direct market pricing
	Tropical dry forests	Pollination	Unspecified	Factor Income / Production Function
High and Shackleton (2000)	Cultivated	Food	Plants / vegetable food	Direct market pricing
Turpie (2003)	Other grasslands	Genepool	Biodiversity protection	Contingent Valuation
	Other woodlands	Genepool	Biodiversity protection	Contingent Valuation
	Savannah	Genepool	Biodiversity protection	Contingent Valuation
	Temperate forest	Genepool	Biodiversity protection	Contingent Valuation
	Open ocean	Genepool	Biodiversity protection	Contingent Valuation
Rausser and Small (2000)	Meditarranean woodlands	Medical	Bioprospecting	Factor Income / Production Function

United Kingdom – Selected data sources from TEEB database

Scientific Work	Ecosystem	Ecosystem Service	ESSubservice	Method
Gren and Soderqvist (1994)	Swamps / marshes	Genepool	Biodiversity protection	Benefit Transfer
Beaumont, Austen, Mangi and Townsend (2008)	Tidal Marsh	Extreme events	Storm protection	Avoided Cost
	Marine [unspecified]	Food	Fish	Factor Income / Production Function
		Raw materials	Other Raw	Factor Income / Production Function
		Climate	C-sequestration	Avoided Cost
		Cultural service	Cultural values	Benefit Transfer
		Recreation	Recreation	Factor Income / Production Function
		Genepool	Biodiversity protection	Contingent Valuation
		Soil fertility	Nutrient cycling	Replacement Cost
Everard (2009)	Salt water wetlands	Climate	C-sequestration	Benefit Transfer
		Erosion	Erosion prevention	
		Soil fertility	Nutrient cycling	
		Water	Water Other	
		Raw materials	Fodder	
		Genetic	Animal genetic resources	Direct market pricing
		Climate	C-sequestration	Benefit Transfer
		Extreme events	Flood prevention	
		Recreation	Recreation	
		Raw materials	Other Raw	
		Genepool	Biodiversity protection	
Everard and Jevons (2010)	Riparian buffer	Recreation	Tourism	Benefit Transfer
Luisetti, Turner and Bateman (2008)	Swamps / marshes	Genepool	Biodiversity protection	Contingent Valuation
Hussain, Winrow-Giffin, Moran, Robinson, Fofana, Paramor and Frid (2010)	Marine [unspecified]	Soil fertility	Nutrient cycling	Benefit Transfer
		Climate	Climate regulation [unspecified]	Benefit Transfer
		Food	Food [unspecified]	Benefit Transfer
		Extreme events	Prevention of extreme events [unspecified]	Benefit Transfer
		Recreation	Recreation	Benefit Transfer
		Cultural service [general]	Cultural values [unspecified]	Benefit Transfer
Homarus Ltd. (2007)	Open ocean	Food	Fish	Direct market pricing
		Recreation	Hunting / fishing	Benefit Transfer
		Recreation	Recreation	Direct market pricing

The information in this annex was extracted from Van der Ploeg, S., De Groot, R. S., & Wang, Y. (2010). The TEEB Valuation Database: overview of structure, data and results. *Foundation for Sustainable Development*, Wageningen, the Netherlands.

Notes

[i] The acronyms in Table 4 are explained here, and some of the papers and websites concerning the data used by the different accounting frameworks are given. Please, also refer to the main publications on IWI, CWI, and SEEA (ANSA & UK-NEA) for further details.

ABS – Australian Bureau of Statistics (publications: *Australian Industry* & *Energy, Water and Environment*)
AFR – Australian Financial Review
BE – Bank of England
BGS - British Geological Survey (*United Kingdom Minerals Yearbook*, 2012)
BP – British Petroleum (publications: *International Energy Annual*, 2006 & *Statistical Review of World Energy*, 2011)
BREE - Bureau of Resources and Energy Economics (publications: *Resource and Energy Statistics* & *Australian Petroleum Statistics*)
GA – Geoscience Australia (publications: *Oil and Gas Resources of Australia* & *Australia's Identified Mineral Resources*)
HM R&C – HM Revenue & Customs
N&W – Narayanan & Walmsley (2008) –see reference list
ONS – Office for National Statistics, UK (publications: *Capital Stocks, Capital Consumption and Non-Financial Balance Sheets*, 2010 & *United Kingdom National Accounts: The Blue Book*, 2013)
OBR – Office for Budget Responsibility (publications: *Fiscal sustainability report*, 2012)
USEIA – U.S. Energy Information Administration (*International Energy Statistics*)
USGS – U.S. Geological Survey (publications: *Mineral Yearbook*)
WB – World Bank

[ii] World Bank staff estimates using data from GEM Commodities database, IMF World Economic Outlook, International Energy Agency, Organization of the Petroleum Exporting Countries, United Nation's Monthly Bulletin of Statistics, BP and IPE.

[iii] World Bank staff estimates using data from GEM Commodities database, USGS Mineral Commodities Summary, US Bureau of Mines 1987.

[iv] The acronyms in Table 6 are explained here, and some of the papers and websites concerning the data used by the different accounting frameworks are given. Please, also refer to the main publications on IWI, CWI, and SEEA (ANSA & UK-NEA) for further details.

ABARES – Australian Bureau of Agricultural and Resource Economics and Science (publications: *Australian Forest and Wood Products Statistics* & *National Plantation Inventory*)
AFG – Australian Forest Grower's Association
FAO – Food and Agriculture Organization (publications: *Forest Resource Assessment*, 1995; *Global Forest Resource Assessment*, 2001, 2006, 2010 & *State of the World's Forests*, 1997)
FAOSTAT – Food and Agriculture Organization Statistics
FC – Forestry Commission (publication: *Forestry Statistics*, 2012 & *National Forest Inventory*)

[v] Studies considered for the estimates include: Fortech (1997); Whiteman (1996); Tay, Healey, and Price (2001); Lopina, Ptichnikov, and Voropayev (2003); Haripriya (1998); Global Witness (2001); and Eurostat (2002).

[vi] The acronyms in Table 7 are explained here, and some of the papers and websites concerning the data used by the different accounting frameworks are given. Please, also refer to the main publications on IWI, CWI, and SEEA (ANSA & UK-NEA) for further details.

REACS – Rural Environment and Agricultural Commodity Survey

ABS publications: *Value of Agricultural Commodities Produced* & *Economic Activity Survey*
ABARES publication: *Value of Agricultural Commodities Produced* & *Agriculture commodity statistics*

[vii] The website used from the Bank of England was:
http://www.bankofengland.co.uk/boeapps/iadb/index.asp?Travel=NIxIRx&levels=1&XNotes=Y&A3790XNode3790.x=8&A3790XNode3790.y=3&Nodes=&SectionRequired=I&HideNums=-1&ExtraInfo=true#BM