National Environmental Performance on Planetary Boundaries

A study for the Swedish Environmental Protection Agency

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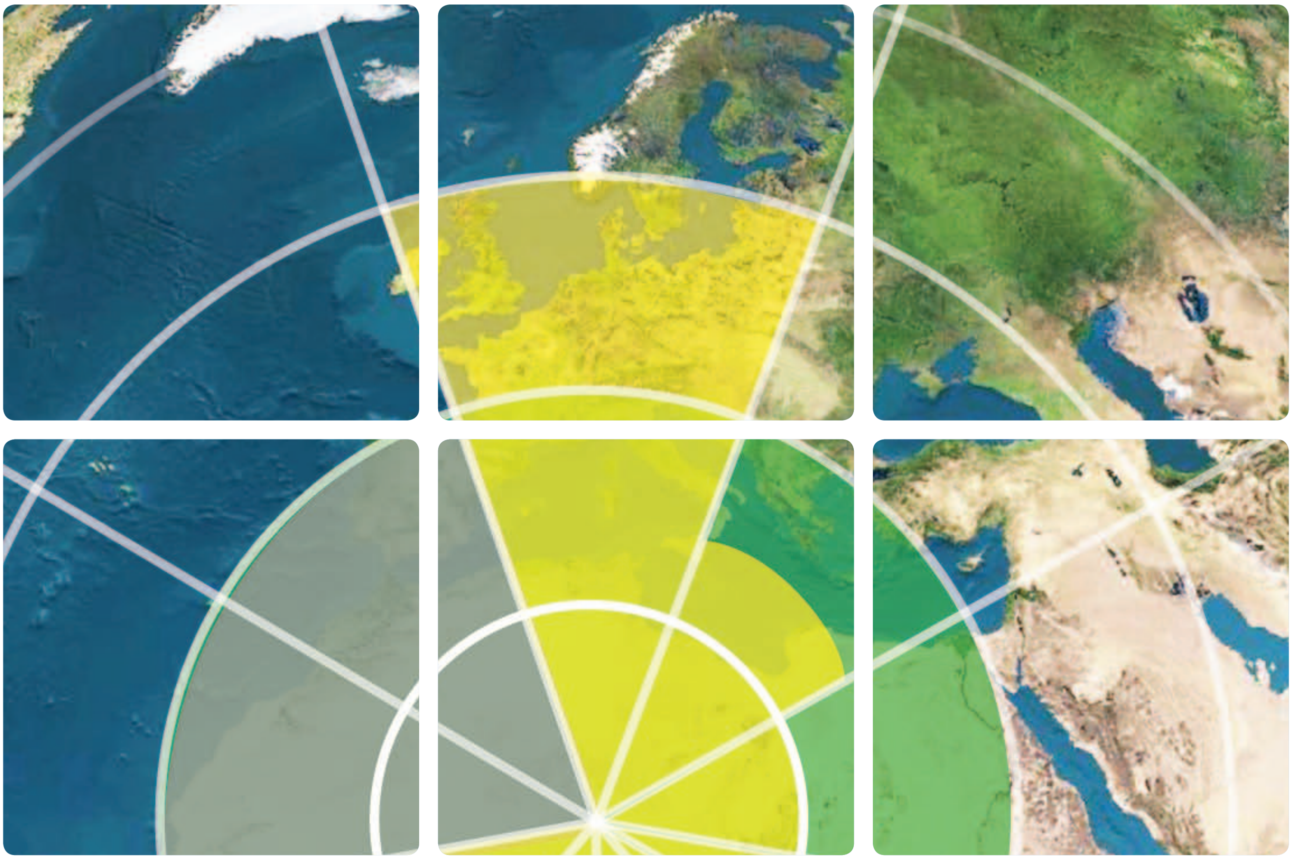

National Environmental Performance on Planetary Boundaries

A study for the Swedish Environmental Protection Agency

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June 2013

SWEDISH ENVIRONMENTAL
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Preface

Swedish environmental policy establishes that the environmental efforts should focus on the 16 national environmental quality objectives. Sweden is exposed to environmental impacts from other countries which affect Sweden´s ability to achieve these environmental quality objectives. At the same time, Swedish consumption and production have an impact on environmental performance in other countries. The overall Swedish environmental policy, the so-called generational goal, specifies that efforts to resolve Swedish environmental problems should not be at the expense of environmental and health problems occurring in other countries.

This study was commissioned by the Swedish Environmental Protection Agency and carried out by the Stockholm Resilience Centre and the Stockholm Environment Institute. The purpose is to test whether the concept of *planetary boundaries* (PBs), as defined by Rockström et al. (2009ab), in different ways could reflect the international dimension of Sweden's national environmental quality objectives.

This involves comparing two sets of boundaries/objectives and developing a methodology for downscaling planetary-level values to nationally relevant ones and identifying appropriate data series that consider both territorial and consumptive performance.

Such a methodology could provide answers to several pertinent policy questions on, for example, Sweden's environmental performance on PBs and what this says about the achievement of the generational goal, which stipulates that national objectives must not be reached while 'transferring' our environmental impact abroad? Conversely, to what extent are the Swedish national environmental quality objectives subject to the performance of other countries, as measured by their relative contribution to exceeding PBs? In the area of international cooperation to mitigate global environmental change, could PB performance indicators help prioritise among countries with which Sweden should cooperate bilaterally? How do existing international environmental agreements match up to the proposed PBs? Are the former less ambitious or simply not being fully implemented? This report is an attempt to develop a methodology to answer these questions as far as is possible and to map current national performance.

The views expressed in this report are those of the authors and do not necessarily represent the views of the Swedish Environmental Protection Agency.

June 2013

Ulrik Westman
Head of International Cooperation
Swedish Environmental Protection Agency

Acknowledgements

This study on downscaling the PBs to the national level is the first of its kind. It draws on published and ongoing research on the planetary boundary framework. The assumptions and findings presented in this report are the sole responsibility of the authors. The authors have benefitted greatly from comments by staff members at the Swedish Environmental Protection Agency (Swedish EPA), in particular, Åke Mikaelsson, Ulrik Westman and Katrin Zimmer. A mid-term seminar was held at Swedish EPA on 31 October 2012 and a final seminar was held at SEPA on 22 February 2013. On both occasions additional comments were made that informed the final revision of the report. The authors have also benefitted from the expertise on the issues addressed by the planetary boundaries of the following Swedish EPA staff working on international environmental governance: Anna Engleryd, Titus Kyrklund, Ulla-Britta Fallenius and Anki Weibull.

At the Stockholm Resilience Centre and the Stockholm Environment Institute, valuable contributions have been made by Louise Karlberg, Harro van Asselt, Oskar Wallgren, Maria Schultz, and Bo Kjellén. The authors would also like to thank Peter Roderick for advice on International Environmental Agreements (IEAs) relevant to planetary boundaries.

Contents

List of figures

List of tables

Summary

Environmental problems are becoming increasingly global. The links between human drivers and impacts in the environment cross geographical scales and country borders. Since the revision of the Swedish national environmental objectives in 2010, the overarching goal of Swedish environmental policy has recognised this fact. The "generational goal" now addresses the importance of limiting Sweden's impact abroad. At the same time, Sweden has limited means and legal competence (*rådighet*) to shape global developments that influence its own environmental objectives. How to evaluate the generational goal, and where and how to direct our limited capacity to influence global development are therefore important questions for Sweden's international environmental policy work.

This report examines whether and how the planetary boundaries framework (Rockström et al. 2009a) offers tools and perspectives on how to work with the two-way interaction between Swedish and global environmental pressures and performance described above. The planetary boundaries concept was presented in 2009 and provides a novel synthesis of the most pertinent global environmental challenges by analysing the risk of crossing critical thresholds in the behaviour of the Earth system's processes. Nine challenges were identified, seven of which were possible to quantify at the time, by identifying control variables (e.g., for climate change, atmospheric CO_2 concentration) and setting specific boundary values (e.g., 350 ppm CO_2). The criteria for identifying planetary boundary processes was that they can be associated with some kind of threshold, or "tipping point", beyond which the planet and its ecosystems might enter new states, some of which are likely to be less hospitable to our current societies, and that this process is possibly irreversible. Boundaries were then set at what was considered to be a "safe distance" from the estimated threshold, using the best available science and the precautionary principle.

The planetary boundaries framework quickly became popular among various stakeholders, arguably because of its scientific grounding combined with its intuitive rationale and easily accessible visual presentation. A common request since its publication has been to downscale the planetary boundaries to the level of individuals, companies and countries, that is, what is required for each to stay within the "safe operating space". This report presents a first attempt to translate the planetary boundaries into a corresponding set of national boundaries. The purpose is to investigate whether the planetary boundaries framework provides a scientifically grounded approach to addressing problems of international environmental policy and comparing performance. Although many different sets of environmental indicators already exist for global problems, these metrics are seldom coupled with a scientifically derived measure of what can be considered good or bad performance above or below an absolute boundary. Instead, such indicators are

typically only used to compare relative performance. The overarching goal of this report is to fill this gap.

Based on the planetary boundary framework we investigate: (i) whether the planetary boundaries can be downscaled to nationally relevant boundaries; and, (ii) whether indicators and data are available that allow comparison of country performance (including that of Sweden) using these downscaled boundaries. If such a methodology is feasible, this provides new perspectives on and methods for how to analyse the international dimension of environmental policy and how to set policy priorities. Finding that this is indeed feasible, the report analyses four related policy questions: How is Sweden performing on the generational goal to not increase environmental problems beyond its borders? Can the legal competence deficit of Sweden in relation to its national environmental objectives be quantified? Which countries should be prioritised for bilateral cooperation with Sweden? How do existing international environmental agreements match with planetary boundaries, and which agreements should be prioritised for Swedish engagement?

Methodology and suggested downscaled planetary boundaries

We first analysed the relevance of downscaling the planetary boundaries in the context of Sweden's national environmental objectives (NEOs) and Swedish environmental policy and found that there was sufficient similarity between these two sets of environmental targets (see Figure S1). We then developed and proposed different options for down-scaled boundaries and presented indicators to measure national performance of the Earth system processes wherever this was feasible (see table S1). Data from international databases and peer-reviewed analyses of large sets on countries were used to enable comparisons between countries (see Figure S2). These results were then used as a basis for responding to the four policy questions.

Methodological issues and limitations

The methodological work of this research project takes as a strict starting point the control variables and boundary values proposed in the original planetary boundaries framework. This means that we did not look for a wider set of relevant indicators around a planetary boundary, but only those which best matched the original control variable. The methodology developed is therefore subject to the same criticisms of individual boundary definitions that have previously been voiced. One such constraint is the lack of spatial differentiation of the planetary boundaries. For example, the land use boundary states that, globally, no more than 15% of ice-free land must be converted to cropland, but does not specify which land would be more or less harmful to convert. This is critical in the context of mounting food security and agricultural challenges connected to providing food for a growing population. This universal approach becomes a limitation when examining the performance of individual countries, in particular given their very different environmental resource endowments and geographical conditions.

Despite these problems, we argue that the most relevant approach is to downscale the planetary boundaries to per capita shares of the global safe operating space. We choose this approach because it provides an answer to the hypothetical question: What if the whole world's population had the same level of resource use as, for example, Sweden? Would the global planetary boundaries then be transgressed?

However, we do not consider the fairness of such a crude distribution of this safe space, and future work needs to explore such concerns in order to increase the relevance of the analysis. Hence, while the methods and boundaries presented in this report offer a first attempt to develop scientifically grounded approaches that attribute the contributions of individuals to global environmental problems, the results should be interpreted with care.

According to the data presented below, less developed countries now perform well, and in per capita terms use sustainable amounts of resources with respect to the boundaries. In contrast, highly developed countries and some emerging economies transgress several of their national boundaries, although there is a less clear pattern for some others (e.g., biodiversity loss). In general, the performance of highly developed countries including Sweden is worse if consumption "footprints" rather than strictly territorial emissions/resource use are considered. The clear pattern associated with level of income for many of the boundaries cannot be ignored in the light of calls for the "right to develop" within the shared environmental space, and suggests that consumption patterns in highly developed countries need to be dealt with.

Finally, the data used in this report are in several cases taken from publicly available sources such as the international databases. These are often based on self-reporting, which limits data quality. It is beyond the scope of this work to coherently address this, and results should therefore be treated with caution.

Responding to the policy questions

The *first policy question* was to explore whether the planetary boundaries framework can be used to identify and measure the extent to which Swedish efforts to achieve domestic environmental objectives cause increased environmental and health problems beyond Sweden's borders. Consumption-based indicators were compiled on performance for several boundaries, and we believe that these are relevant for addressing and assessing the generational goal, since they capture the environmental effects of the Swedish economy not just domestically but also abroad. We believe that the planetary boundaries framework can contribute to existing work in two important ways. First, it is a comprehensive framework that captures many major global environmental challenges, as opposed to a more data-driven and single-issue approach. Second, it establishes absolute per capita boundaries, thereby allowing measurement of the absolute performance of countries rather than simply their relative performance.

The *second policy question* was whether the planetary boundaries framework and its indicators can help to characterise and quantify Sweden's legal competence deficit in relation to some of its NEOs. Reviewing all the bar charts and graphs presented in chapters 4 and 5 suggests that Sweden's contribution to the planetary boundaries is in most cases minor in absolute terms. This means that Sweden's competence to hand over to the next generation a situation where most environmental problems have been resolved is limited. The methodological approach piloted here allows a quantification of the deficit for only one national environmental objective: Reduced Climate Impact. The deficit was over 99% at the global level. We found that it was a worthwhile analytical exercise and that the planetary boundaries framework in general is amenable to visualising environmental challenges in terms of numbers and graphically. However, the planetary boundaries framework cannot add much when it comes to more regional challenges, such as the eutrophication of a regional sea or regional transboundary air pollution.

In response to the *third policy question*, the analysis presented in this report can potentially be used to identify sets of countries with similar challenges and as a source of information to inform discussions on priorities in bilateral environmental cooperation. Interpretations based on this first analysis should, however, be made with care, and the results are more robust when comparing performance across several boundaries and for a group of countries, as opposed to focusing on individual boundaries and individual countries. Using the downscaled boundaries and indicators selected in this report, performance data for 61 countries were generated and some general performance patterns were identified, such as richer countries generally performing much worse. However, it was also recognised that the selection of priority countries for bilateral cooperation will necessarily involve many other considerations, such as political relations, the level of economic development, key Swedish leverage opportunities, and so on.

Finally, with regard to our *fourth policy question*, the analysis of how well the planetary boundaries are matched with international environmental agreements suggested that agreements are in place for all but one boundary, but that their implementation has not been successful. There is no lack of global environmental goals, nor is their level of ambition found wanting, as the United Nations Environment Programme (UNEP) found in a recent report. The problem is rather the limited progress on existing goals. Our detailed assessment of existing international environmental agreements led to an effort to distinguish between the policy gap and the implementation gap for each planetary boundary. Overall, our analysis suggests that there are four important paths for future engagement in international environmental agreements and international cooperation more broadly: (i) to reduce implementation deficits in relation to existing targets and commitments; (ii) to highlight the global scale and implications of problems currently being addressed regionally; (iii) to extend the rationale for acting from human health effects to effects on ecological and Earth system resilience, but also connect these two; and

(iv) to pursue tools for international cooperation, other than merely relying on formal international environmental agreements such as voluntary initiatives (some of which involve non-state actors) and capacity building efforts targeted at developing countries to support their implementation of international agreements and targets.

Conclusions

Using planetary boundaries as a basis for **comparing the performance of countries**, the main conclusion is that, in general, it is most important to work with developed countries and countries with rapidly growing economies. These countries have higher absolute and per capita impacts on the environment globally, and thus a bigger responsibility for progressive action on, e.g., mitigating climate change. For future work and the application of the methodology presented below, we recommend analysis that tracks the development of performance over time, as this would enable the identification of countries with negative trends and fast rates of change in performance, as well as more in-depth exploration of equity issues.

A further recommendation is that additional consumptive-based indicators, covering each of the planetary boundaries, can be used to complement the existing indicators to **assess whether Sweden meets its generational goal**. The tentative methods and results on, e.g., consumptive land use and the threats to biodiversity driven by consumption provided in this report are concrete examples.

A third recommendation is that **if the "competence deficit" is to be reduced, Sweden must act more proactively and assertively in negotiations around international environmental agreements**. Many of the national environmental objectives depend on international action and the analysis of national performance presented below suggests that Sweden's performance is of minor importance in many cases. The review of international environmental agreements shows that much of the legal infrastructure is in place to address planetary boundaries, but that the level of ambition and implementation effectiveness need to be strengthened. However, it should also be emphasised that legally binding agreements are only one of many routes to take. Sweden could expand bilateral cooperation with key countries to improve their domestic performance on key issues. Voluntary initiatives involving non-state actors could be pursued as an alternative to legally binding agreements. Finally, a strategy could be pursued to identify the "co-benefits" of environmental action at both the local and, ultimately, the global level. The new Climate and Clean Air Coalition, in which Sweden is a key player, embraces this kind of approach.

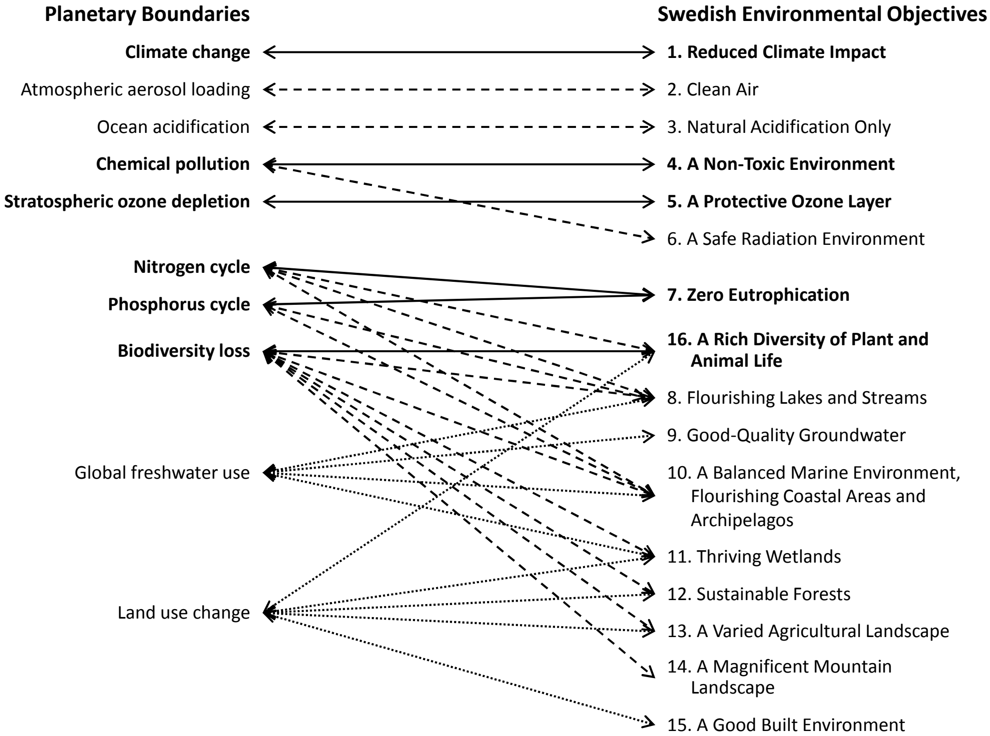

Figure S1. Thematic matching of NEOs and PBs
Figur S1. Tematisk matchning mellan svenska miljömål och planetära gränsvärden

Table S1. Compilation of options for downscaling
Tabell S1. Sammanställning av alternativa nedskalade gränsvärden samt dataserier

Planetary Boundary	**Per capita (current population)**		**Absolute**	
	Territorial performance	Consumptive performance	Per capita * national population	Country-dependent (relative to national resource base)
Climate Change	**2 t CO_2 / capita / y** *UNEP (2007)*		**Eg., Sweden: 18 Mt CO_2 / y**	n/a
Nitrogen cycle	**5 kg / capita / y** Rockström et al. (2009) divided by world population		**Eg., Sweden: 45,000 t N / y**	Not yet quantified, but suggestion is WPL<1
Freshwater use	**585 m^3 / capita / y** Rockström et al.(2009) divided by world population		**Eg., Sweden: 5.5 km^3 / y**	**40% water withdrawal, eg., Sweden: 73 km^3 / y**
Land use	**0.3 ha / capita** Rockström et al. (2009) divided by world population		**Eg., Sweden: 2.7 Mha**	**15% land use, eg., Sweden: 6 Mha**

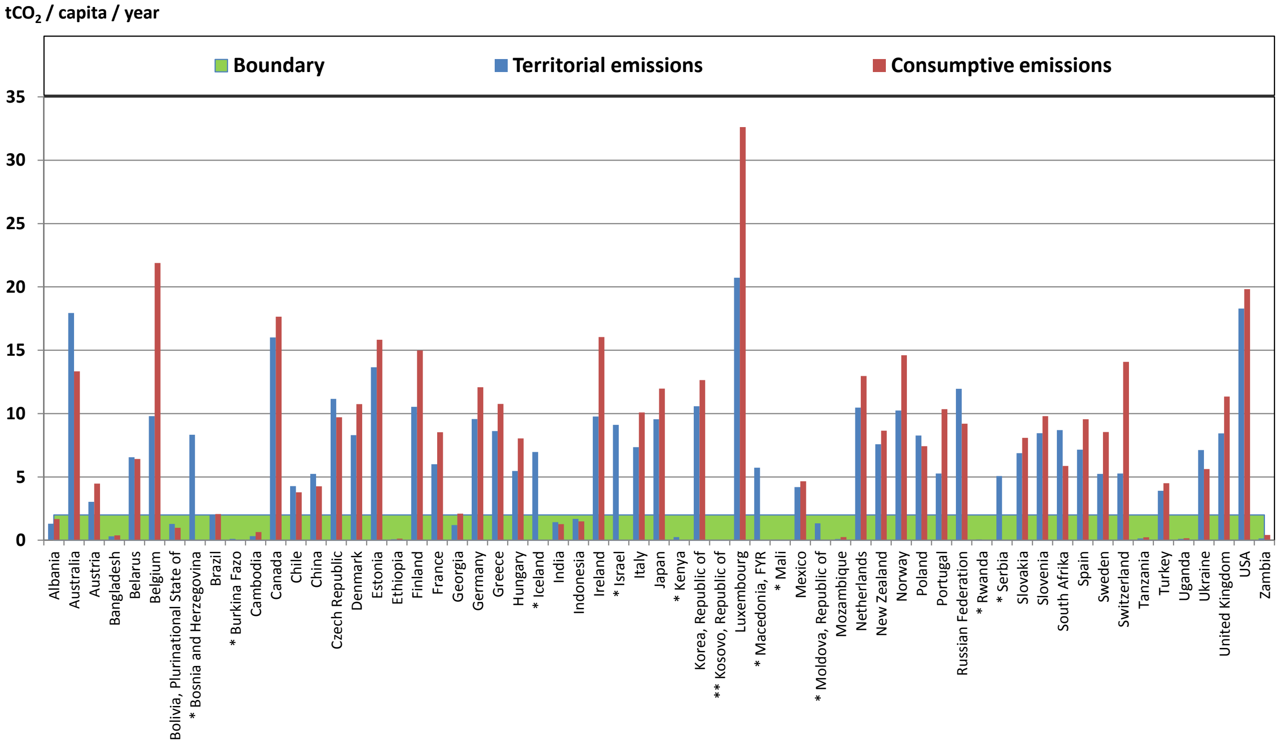

Figure S2. Example of comparisons between countries of performance on a downscaled planetary boundary for climate change.

Notes: Green area indicates safe space, with a downscaled boundary at 2 t CO_2/capita/year. Red bars indicate consumptive performance and blue bars territorial performance.

Source: Based on data from Peters et al. (2011), for some countries data is lacking (*, **), see further chapter 4.

Figur S2. Exempel på jämförelse av länders prestanda för det nedskalade planetära gränsvärdet för klimatförändringar.

Not: Den gröna ytan indikerar det ”säkra manöverutrymmet”, d.v.s. ytan under det nedskalade gränsvärdet, som ligger på 2 t CO_2/capita/år givet dagens globala befolkningsmängd. Röda staplar mäter konsumtionsbaserade utsläpp och blå ”territoriella” utsläpp.

Källa: Baserad på data från Peters et al. (2011), för visa länder markerade med (*, **) saknas data, se kapitel 4.

Sammanfattning

Miljöproblem är i allt större utsträckning globala och människans miljöpåverkan korsar geografiska skalor och gränser mellan länder. Sedan 2010 då de svenska miljömålen reviderades är detta något den svenska miljöpolitiken tar allt större hänsyn till. Det övergripande generationsmålet för svensk miljöpolitik säger till exempel att Sverige ska lösa sina stora miljöproblem "utan att orsaka ökade miljö- och hälsoproblem utanför Sveriges gränser". Men Sverige har förstås begränsad rådighet över den globala utvecklingen som i sin tur i hög grad påverkar om vi kan nå våra egna nationella miljömål. Frågan om hur vi ska utvärdera generationsmålet och var och hur vi ska fokusera våra insatser för att påverka den globala utvecklingen är därför vikiga frågeställningar för svensk internationell miljöpolitik.

Den här rapporten undersöker om det är möjligt att använda ramverket med planetära gränser (Planetary boundaries; Rockström mfl. 2009a) som ett verktyg för att belysa interaktionerna mellan Sveriges och de globala drivkrafternas miljöpåverkan på olika skalor. Konceptet med planetära gränser introducerades 2009 och innebar ett nytt sätt att se på de viktigaste globala miljöutmaningarna. Till skillnad mot tidigare analyser fokuserade detta arbete på att analysera tröskeleffekter i biologiska och kemiska processer på global skala och/eller med global betydelse. Nio viktiga globala processer identifierades, varav sju kunde definieras i termer av specifika kontrollvariabler (för klimatförändringar används till exempel koncentration av CO_2 i atmosfären) samt kvantifieras med specifika gränsvärden (till exempel 350 miljondelar, ppm, CO_2). För att kvalificeras som en planetär process användes kriteriet att det ska finnas ett tröskelvärde som utgör en brytpunkt bortom vilken vår planet och dess ekosystem riskerar att inträda i ett nytt tillstånd med sämre förutsättningar för gynnsam utveckling av våra samhällen, samt att de globala förändringarna riskerar vara irreversibla bortom denna brytpunkt. Genom att hänvisa till de senaste forskningsrönen och därefter tillämpa försiktighetsprincipen föreslogs planetära gränsvärden som var satta på ett "säkert avstånd" från dessa tröskeleffekter (i den lägre delen av osäkerhetsintervallet).

Ramverket med dessa planetära gränser har fått snabb spridning bland en mängd olika aktörer, till stor del på grund av att ramverket kombinerade vetenskapligt grundade slutsatser med en överskådlig och lättförståelig grafisk presentation. Sedan de nio gränserna presenterades är det många som har efterfrågat en nedskalning till individ-, företags-, eller landsnivå. Det vill säga, vad innebär det till exempel på en nationell skala att stanna inom de planetära gränserna? Den här rapporten utgör ett första försök att översätta de planetära gränserna till nationellt specifika gränsvärden. Syftet är att undersöka om ramverket därmed kan utgöra en vetenskapligt förankrad metod för att jämföra olika länders miljöprestanda. Även om det redan existerar en rad olika förslag på indikatorer för att beskriva enskilda länders bidrag till globala miljöproblem så är de sällan grundade på en vetenskaplig analys av vad som är bra eller dålig prestanda, i absoluta termer. Istället

mäter de flesta existerande indikatorer enbart relativ prestanda. Det övergripande målet med den här rapporten är alltså att med hjälp av de planetära gränserna försöka ta fram sådana indikatorer på miljöprestanda, med absoluta gränsvärden, och diskutera hur sådana indikatorer kan hjälpa till att besvara policyrelaterade frågor.

Med avstamp i ramverket med planetära gränser undersöker vi: (i) om de planetära gränserna kan skalas ned till relevanta nationella gränsvärden; och, (ii) om det finns lämpliga indikatorer och data tillgängliga som möjliggör en jämförelse mellan olika länder (inklusive Sverige) för dessa nio planetära gränser. I de fall då en sådan form av analys visar sig möjlig kan det öppna upp för nya perspektiv och metoder för att analysera den internationella dimensionen i svensk miljöpolitik och ny förståelse för hur Sverige bör prioritera i detta arbete. Rapporten finner att det är möjligt med en sådan analys och tar upp fyra olika frågeställningar för svensk internationell miljöpolitik: Når vi generationsmålet? Kan den begränsade rådighet som Sverige har över våra egna miljömål kvantifieras? Hur bör vi prioritera vår bilaterala samverkan med andra länder? Matchar de redan existerande internationella miljökonventionerna de planetära gränserna, och vilket slags arbete med miljökonventioner bör Sverige fokusera på framöver?

Metod och föreslagna nedskalade planetära gränser

Vi analyserade först om det är relevant och möjligt att skala ned de planetära gränserna genom att jämföra dem med våra svenska miljökvalitetsmål och de övergripande målen för svensk miljöpolitik, och fann en tillräckligt god överensstämmelse mellan de två grupperna av mål (se Figur S1). Efter detta utvecklade vi förslag på olika metoder för att skala ned gränsvärdena samt lämpliga indikatorer för att mäta nationell prestanda när så var möjligt (se Tabell S1). De siffror som presenteras i rapporten kommer genomgående från öppna internationella databaser eller vetenskapliga publikationer som rapporterar data för ett stort antal länder. Detta för att möjliggöra jämförelser mellan länder (se Figur S2). Nackdelen är att bättre uppskattningar för till exempel Sverige inte använts då motsvarande data inte finns för alla andra länder. Uppskattningen av nationell prestanda används sedan för att diskutera våra fyra policyfrågor.

Begränsningar och problem med den utvecklade metoden

Metoderna som arbetats fram i den här rapporten tar sin utgångspunkt i en strikt tillämpning av det ursprungliga ramverket med planetära gränser (Rockström m fl. 2009a). De strävar efter att beskriva samma processer men på den nationella skalan. Detta betyder att vi inte har sökt identifiera ytterligare variabler av allmän relevans än de som redan finns beskrivna i ramverket (till exempel, länders energiintensitet som en indikator på omställningsarbete för klimatförändringar). En följdeffekt är att den kritik som riktats mot originalramverket, där vissa av gränsvärdena ifrågasatts, också kan riktas mot våra nationella gränser. Till exempel har det planetära gränsvärdet för markanvändning kritiserats. Det gränsvärdet föreslår att maximalt 15% av planetens isfria landyta bör omvandlas till jordbruksmark, men tar inte hänsyn till huruvida markområdena är mer eller mindre lämpliga för jordbruk. Eftersom fortsatt ökad jordbruksproduktion är nödvändig för att förse en växande världsbefolkning med mat är det givetvis viktigt att titta på vilket sätt som arealer konverteras till jordbruksmark och vad alternativ användning skulle kunna innebära. Ett generellt antagande om att begränsa jordbruksmarken till 15% i respektive land blir därför problematiskt eftersom förutsättningarna för jordbruk varierar kraftigt.

Trots dessa och andra konceptuella problem så argumenterar vi i den här rapporten för att det är relevant att diskutera nedskalade planetära gränser, framförallt i termer av per capita-andelar av de globalt tillgängliga resurserna och utsläppen. Vi har valt utgångspunkten att det går att dela upp det globalt tillgängliga utrymmet genom att svara på en relevant hypotetisk fråga: Vad hade hänt om hela världens befolkning hade samma nivå av resursanvändning och/eller utsläpp som till exempel Sverige? Skulle de planetära gränserna redan vara överskridna då?

En uppdelning av det tillgängliga utrymmet inom de planetära gränserna kräver i förlängningen också en diskussion om vad som är en rättvis fördelning. En sådan analys har inte varit möjlig inom ramen för denna rapport, men framtida arbete bör testa olika prinicper för rättvis fördelning för att öka relevansen av resultaten som presenteras här. Även om metoderna och de nationella gränsvärden som presenteras i denna rapport är ett försök att göra en vetenskapligt grundad analys av individer och nationers bidrag till de globala miljöproblemen är detta alltså endast ett första steg och man bör vara försiktig med att dra alltför långtgående slutsatser.

Generellt så pekar de data vi presenterar i rapporten på att länder med lägre inkomster har högre prestanda, det vill säga, de använder till exempel mindre resurser per capita i relation till de planetära gränserna. Mer "utvecklade" länder och vissa länder i stark ekonomisk tillväxt överskrider fler gränsvärden. Men för vissa av de planetära gränserna är det mindre entydiga mönster, till exempel vad det gäller förlust av biologisk mångfald. Sveriges prestanda är tydligt sämre om man använder konsumtionsbaserade indikatorer istället för territoriella (produktionsbaserade) indikatorer. Det är svårt att ignorera att högre inkomster och ökad konsumtion, inklusive av importerade varor och tjänster, leder till sämre miljöprestanda. Givet argumentet att mindre utvecklade länder har rätt att öka sin andel av resursanvändningen för att höja välfärden så pekar resultaten tydligt på att utvecklade länder behöver förändra sina konsumtionsmönster.

Slutligen, den data som används i rapporten kommer i många fall från offentliga internationella databaser. Denna data är ofta självrapporterad vilket begränsar tillförlitligheten. Vi har i den här studien inte haft möjlighet att konsekvent undersöka tillförlitlighet och det innebär att resultaten ska behandlas med försiktighet, framförallt när man studerar resultaten för individuella länder.

Diskussion av de fyra studerade policyfrågorna

Vår *första policyfrågeställning* är huruvida de planetära gränserna kan användas som en måttstock för att utvärdera om Sverige når generationsmålet. För flera av de planetära gränsvärdena har vi i denna rapport använt konsumtionsbaserade indikatorer så långt som möjligt för att mäta prestanda för nationella gränsvärden. Vi bedömer att detta är relevant för att utvärdera generationsmålet då det just mäter svensk påverkan i global mening. Ramverket med de planetära gränserna kan bidra till redan föreslagna indikatorer på två sätt. För det första så är det ett i stort sett heltäckande ramverk som innefattar de största globala miljöutmaningarna. Detta i kontrast till att behandla ett problemområde i taget, eller begränsa analyser av Sveriges miljöpåverkan till de områden där vi idag har mätserier och data. Att utgå från ramverket med de planetära gränserna tvingar oss att relatera till en i global mening mer eller mindre komplett lista med globala miljömål. För det andra så ger den omarbetning av ramverket som presenteras i denna rapport förslag till absoluta nationella gränsvärden, vilket till skillnad mot existerade förslag till indikatorer för att mäta generationsmålet möjliggör att mäta absolut måluppfyllelse och inte bara relativ förändring över tid eller prestanda i relation till andra länder.

Den *andra policyfrågeställningen* berörde frågan om huruvida ramverket med de planetära gränserna kan användas för att kvantifiera bristen på rådighet över vissa av våra egna Svenska miljömål. Resultaten som vi presenterar i kapitel 4 och 5 visar på det redan kända faktum att Sveriges bidrag till de globala miljöproblemen i absolut bemärkelse är mycket litet. För flera av våra miljömål innebär detta att vi har mycket begränsad rådighet över de miljömål som har en stark koppling till den globala utvecklingen. Vi föreslår och testar här en metod för att kvantifiera bristen på rådighet givet de planetära gränsvärdena, men fann att det var möjligt endast för ett miljömål: ”Begränsad klimatpåverkan”. I detta fall var bristen på rådighet över 99%, trots att Sverige har högre per capita utsläpp än de flesta länder i världen. Vår slutsats är att ramverket med de planetära gränserna kan erbjuda en beräkningsgrund för att kvantifiera rådighetsunderskottet för globala miljöproblem som har samma målformulering som motsvarande svenska miljökvalitetsmål (t ex ”Begränsade klimatförändringar”). Men ramverket har inte mycket att erbjuda när det gäller miljöproblem som i svenska miljömål är uttryckta som regionala utmaningar (till exempel övergödning eller luftföroreningar).

När det gäller den *tredje policyfrågeställningen*, kan resultaten i denna rapport användas för att identifiera grupper av länder med liknande utmaningar och underlätta prioriteringar för bilateral samverkan på miljöområdet. Vilka länder är viktigast att samarbeta med och på vilken grund? Som redan påpekats ovan bör dock resultaten i denna rapport användas med försiktighet. Robusta slutsatser kan främst dras för grupper av länder och samtidig analys av flera gränsvärden. En sådan generell slutsats är att rikare länder och länder i stark ekonomisk tillväxt har mycket sämre miljöprestanda i global mening och därför bör vara föremål för fortsatt utvecklad bilateral samverkan.

Samtidigt vill vi tydligt påpeka att prioriteringsgrunder för bilateral samverkan givetvis bör ta i beaktning andra politiska bedömningsgrunder, till exempel behovet av hållbar utveckling i vidare bemärkelse och om Sverige har särskilt goda förutsättningar för att påverka i samarbetet med vissa länder.

Slutligen handlar den fjärde *policyfrågeställningen* om hur väl de planetära gränserna matchas av redan existerade internationella miljökonventioner eller om befintligt multilateralt samarbete har för låg ambitionsnivå. Vår analys visar på att (en eller flera) miljökonventioner finns på plats för alla frågor utom en som de planetära gränsvärdena tar upp, men implementeringen av dem har ännu inte varit framgångsrik. Precis som FN:s miljöprogram nyligen funnit i en rapport (UNEP, 2012e) saknas det alltså inte målformuleringar på global nivå och inte heller är målens ambitionsnivå bristande rent generellt. Problemet är snarare begränsad framgång med att nå redan satta mål. Vår detaljerade genomgång av befintliga internationella miljökonventioner ledde också till ett försök att mäta ”policyunderskott” kontra ”implementeringsunderskott” för varje planetärt gränsvärde, det vill säga till hur stor del problemet består av oambitiösa mål eller icke framgångsrik implementering. Sammantaget visar kartläggningen att det finns fyra huvudsakliga vägar för fortsatt svenskt deltagande i internationellt miljösamarbete: (i) att söka minska implementeringsunderskotten som råder under befintliga miljökonventioner, (ii) att uppmärksamma den globala betydelsen av miljöproblem som idag behandlas framför allt regionalt, (iii) att försöka utvidga motiven till internationellt samarbete kring olika hälsoeffekter till att också inbegripa mer långsiktiga effekter på planetens ekologiska resiliens, samt visa på kopplingarna mellan dessa, samt (iv) att fortsätta använda andra verktyg för internationellt samarbete utöver lagligt bindande miljökonventioner, till exempel frivilliga initiativ (också sådana som inbegriper icke-statliga aktörer) och kapacitetsbyggande åtgärder i utvecklingsländer för att stödja deras implementering av internationella överenskommelser och mål.

Slutsatser

Genom att använda ramverket med de planetära gränserna för att **bedöma och jämföra länders miljöprestanda i förhållande till globala miljöutmaningar** konstaterar vi att det i global mening är viktigast att arbeta med ”utvecklade” länder och länder med snabbt växande ekonomier. Generellt har dessa länder sämst prestanda och störst global påverkan i både absolut bemärkelse och per capita, och därmed har de ett större ansvar till konkret handling. I framtida studier som applicerar de metoder vi arbetat fram i denna rapport rekommenderar vi att man undersöker utvecklingen av prestanda över tid då detta skulle möjliggöra att identifiera länder med negativa trender eller snabba positiva förändringar i prestanda. En sådan analys skulle också utgöra underlag för en vidare diskussion om vilket som är en rättvis fördelning av det tillgängliga utrymmet innanför de planetära gränserna.

En ytterligare slutsats är att de konsumtionsbaserade indikatorer och per capita-gränsvärden som vi utvecklat i denna rapport kan komplettera de existerande indikatorerna som används som bedömningsunderlag för analysen av **om Sverige når generationsmålet**. Våra preliminära resultat vad det gäller en gräns för markanvändning och ny indikator för hot mot biologisk mångfald är konkreta exempel.

En tredje rekommendation är att om rådighetsbristen över svenska miljömål ska minskas, måste Sverige agera mer proaktivt och tydligt i förhandlingar kring internationella miljökonventioner. Flera av de svenska miljömålen är beroende av internationella åtgärder och analysen av svensk prestanda visar att Sveriges påverkan på gränsvärdena är av mindre betydelse i flera fall. Genomgången av internationella miljökonventioner visade att mycket av den legala infrastrukturen redan finns på plats för att agera på föreslagna planetära gränsvärden, men att ambitionsnivån behöver höjas i vissa fall och att implementeringen generellt behöver stärkas avsevärt. Dock ska det också understrykas att lagligt bindande överenskommelser endast utgör en möjlig väg framåt. Sverige kan också utvidga bilaterala samarbeten med viktiga länder för att förbättra deras nationella prestanda av vikt för både miljömålen och de planetära gränsvärdena. Frivilliga initiativ där icke-statliga aktörer deltar kan användas i större utsträckning. Slutligen kan man söka efter miljöåtgärder som ger direkt nytta både på lokal och global nivå. Koalitionen för klimat och ren luft (Climate and Clean Air Coalition), där Sverige är en nyckelspelare, är ett exempel på en sådan ansats.

1 Introduction

1.1 Environmental boundaries and goals

We live in an increasingly globalised world, where the scale of our environmental impact has led Earth system scientists to claim we have entered the Anthropocene – an era when humans have become the dominant geological force (Steffen et al. 2007). Furthermore, our environmental footprints are no longer only local. Through international trade, the environmental impacts of our consumption are often caused elsewhere. Some of our local as well as distant impacts aggregate and pose global environmental threats, sometimes with a risk of crossing “tipping points” with uncertain but potentially catastrophic outcomes. Evidence is growing that it is no longer useful to either measure environmental impact or devise policy responses within strictly national borders. Instead, more international cooperation is warranted, together with more research on where and when global tipping points might exist.

These and other insights led to the concept of *planetary boundaries* (PBs), which was first presented in an article in *Nature* in 2009 (Rockström et al. 2009a) followed by a longer version in *Ecology & Society* shortly after (Rockström et al. 2009b). A team of 28 scientists convened by the Stockholm Resilience Centre and the Stockholm Environment Institute introduced the concept[1] and proposed nine[2] key PBs as a proof-of-concept. Seven of these nine boundaries were quantified and specific boundary values were proposed. Figure 1 illustrates global performance on the nine PBs, where the green area represents the safe operating space defined by all the planetary boundaries. The yellow bars represent the most recent measurements available on each PB. The initial review of global performance therefore suggests that humanity as a whole has transgressed three boundaries: climate change, rate of biodiversity loss and alteration of the nitrogen cycle.

The scientific impact of the PB framework has been high and it has become a reference point in the study of global sustainability. The policy impact has also been significant, with references in several high-profile publications and initiatives on global sustainability, including the *United Nations High-Level Panel on Global Sustainability* (United Nations Secretary-General’s High-level Panel on Global Sustainability 2012), the OECD report *Towards Green Growth* (OECD 2011) and the UNEP *GEO5* report (UNEP 2012).

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[1] By “concept of PB” we mean the phenomenon of boundaries at a planetary scale. By “PB framework” we mean the particular proposal of nine PBs and appropriate control parameters and the data in Rockström et al. (2009a).

[2] Two sub-boundaries were developed for the biogeochemical flow boundary. One for the nitrogen and one for the phosphorous cycle. Each is referred to as an individual boundary in this report.

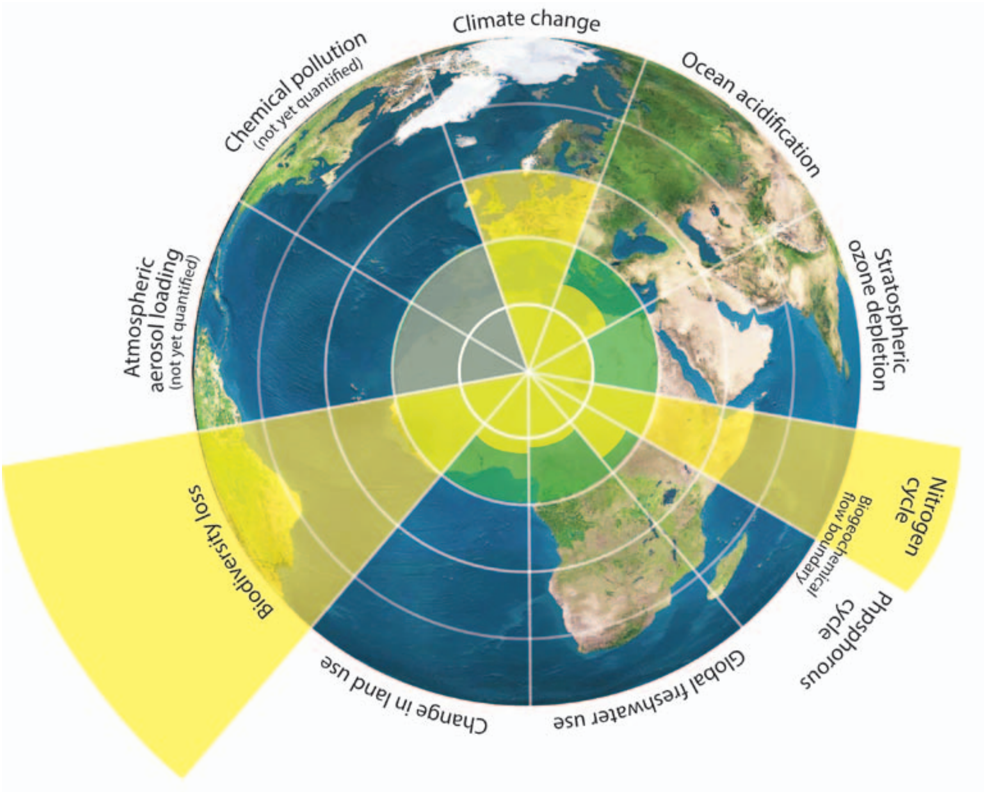

Figure 1. Illustration of global performance on the nine planetary boundaries with the "safe operating space" in green

Source: Based on Rockström et al. (2009a). Note that the nine boundary values are represented by the outer border of the green area and that scales of the PB parameters have been normalised.

A similarly comprehensive set of quantified environmental boundaries had not previously been formulated at the global level, neither as a scientific proposal nor as a policy initiative. Quantified environmental targets and limits are more common at the national and regional levels, although the rationales may differ – from applying the precautionary principle to what is politically acceptable. Sweden's 16 national environmental objectives (NEO) are a significant example of a comprehensive set of goals, most of which have been elaborated in quantified targets.

In 2010, an additional "generational goal" was adopted by the Swedish Parliament: "[t]he overall goal of Swedish environmental policy is to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental and health problems outside Sweden's borders" (Regeringens proposition 2010: 21). Highlighting the international dimension in this way links national environmental performance with global environmental challenges, such as those addressed in the PB framework.

1.2 Aim of the study

The aim of this report is to support work on the NEOs by drawing on new research on planetary boundaries in order to provide new perspectives on and new indicators for the international dimension of Swedish environmental policy. The logical flow of the research and policy questions addressed in this report is illustrated in Figure 2. The international dimension is seen as a two-way interaction between Swedish and global environmental pressures and performance. First, in order to achieve the generational goal, Sweden's impact abroad and on the global environment needs to be measured and monitored. Importantly, this needs to account for the environmental effects of Swedish consumption, in addition to the impacts of our production of goods and services. Second, the achievement of several NEOs as well as impoving Swedish environmental quality more broadly will be dependent on aggregate global environmental performance, as well as the environmental performance of specific countries. It has been well established that the legal competence (*rådighet*) of Sweden is not sufficient to guarantee the achievement of all the NEOs. For this reason – and many others – Sweden engages in international environmental cooperation. International cooperation is undertaken both multilaterally, through legally binding international environmental agreements (IEAs) and various voluntary initiatives, and bilaterally, through cooperation programmes with selected countries.

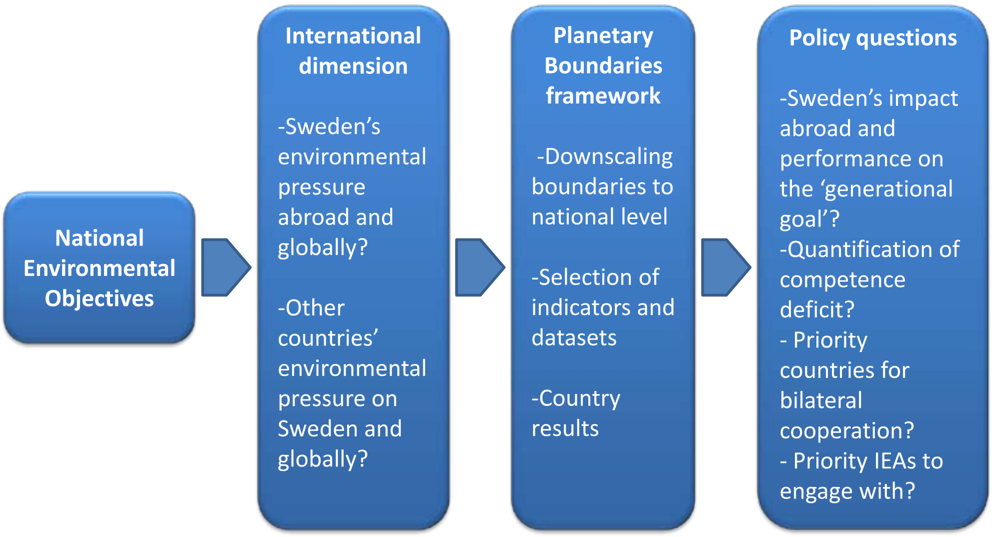

Figure 2. Research questions and structure of the report

The purpose of this report is to examine whether the PB framework is useful for characterising and measuring the two-way interaction between Swedish and global environmental pressures and performance, and for deriving policy recommendations. The PB framework offers a comprehensive set of global environmental indicators based on recent scientific evidence. Unlike some other international indicator sets,[3] the PB framework offers fixed boundaries or target values, which this report attempts to downscale to the national level. This means that it is possible to measure not only the *relative* performance of countries, but also their performance in relation to an *absolute target*. Finally, the PB framework could inform Swedish environmental policy and international engagements at a more conceptual level, by drawing attention to threshold effects and tipping points, as opposed to assumptions about linear, gradual and reversible environmental change. Suggesting non-negotiable boundaries raises the question of how Sweden can contribute to a fair and efficient distribution of the safe environmental operating space.

A methodology is proposed for measuring national performance on the global scale environmental challenges outlined by the PBs as defined and published in 2009 (Rockström et al. 2009ab). We examine first whether it is feasible and appropriate to downscale the planetary-level boundaries to meaningful national boundaries. We then test which national indicators and existing datasets can either directly measure performance on PBs, or characterise performance on the problem areas addressed by the boundaries. The methodology includes both territorial and consumption perspectives, and highlights the differences between the two. A territorial perspective takes account of the emissions and the use of natural resources and ecosystem services within a country's borders as a consequence of production.[4] A consumption perspective takes account of the use of resources and ecosystem services globally as a result of a country's consumption and trade with other countries. Initial results on national performance based on our proposed indicators are presented for selected countries, together with commentary on the results.

By downscaling PBs and measuring national performance, the results can be used to address a number of pertinent policy questions.

- **How is Sweden performing on the generational goal?** This question can be answered by measuring Sweden's contribution to the transgression of PBs. In particular, we contrast a production vis-à-vis a consumption perspective to demonstrate the extent to which Swedish consumption causes environmental impacts abroad that do not fall under the NEO system or Swedish environmental regulation. This work extends earlier work on consumption-related indicators by the Swedish Environmental Protection Agency (EPA).
- **Can Sweden's legal competence deficit in relation to its NEOs be quantified?** The Swedish EPA has already analysed which NEOs are difficult for Sweden to achieve on its own, for example, due to pollution originating from abroad. This report examines whether the PB indicators can help to quantify such deficits and hence provide guidance on which issues, which IEAs, and which partner countries Sweden should focus on in order to address the deficit.

[3] For example, the Environmental Performance Index (EPI) which ranks countries' relative performance on 22 indicators, see http://epi.yale.edu/

[4] That is analogous with how the performance of nations on greenhouse gas emissions is reported to the United Nations Framework Convention on Climate Change.

- **Which countries should be prioritised for Swedish bilateral cooperation?** The measurement of national performance on PBs reveals the absolute and relative contribution of countries to their transgression. Poor or quickly deteriorating performance could be one of the criteria for the selection of priority countries. Naturally, many other criteria will be important, such as political relations, country commitment, poverty levels, and so on. In addition, Sweden may want to cooperate with countries in its own region, such as the Baltic Sea, or work with countries on predominantly local environmental problems which have less clear global implications than the PB variables do. This report discusses the appropriateness of the PB framework for answering this policy question.
- **Which IEAs should Sweden prioritise for further engagement?** As is mentioned above, another route for international cooperation is to engage with existing or new IEAs. IEAs need to be continually adapted to new scientific evidence on the nature of the problem they seek to address. This report assesses the extent to which the proposed PBs are matched by existing IEAs, and attempts to characterise both the policy gaps (missing or inadequate IEAs) and implementation gaps, where adequate IEAs exist but have not resulted in the intended environmental impacts. This gap analysis sheds light on which IEAs or policy areas will be important to progress if the PB framework is chosen as a reference point.

1.3 The structure of the report

This report is structured in the following way. First, the *relevance* of the PB framework in the context of Swedish national environmental objectives and policy priorities is discussed in chapter 2. After a brief review of the system of Swedish NEOs, the rationale of and critical issues surrounding the PB framework are described and its relevance is assessed in chapter 3. A *methodology* is also developed for analysing national performance on all the PBs, including the downscaling of boundary values and identification of relevant datasets and a discussion on key limitations. A step-wise approach is applied to each of the nine PBs in chapter 4. *Country-specific results* are presented for each of the PBs, together with a short commentary on methodological and data limitations. Having presented these results, each of the four *policy questions* outlined above is revisited in chapter 5. Chapter 6 presents key conclusions and makes recommendations, including on the need for future research.

2 Relevance of the planetary boundaries framework at the national level

This chapter reviews the Swedish system of NEOs and the need to understand the two-way linkages with the international level. The PB framework is described in more detail and discussed in terms of its general appropriateness for performance measurement. Based on these reviews, the fit between the 16 NEOs and the nine proposed PBs is analysed. This leads to a discussion of the relevance of the PB framework to Swedish environmental policy and the NEOs.

2.1 Swedish national environmental objectives and the international dimension

The system of NEOs established in the late 1990s originally included 15 objectives, but a 16th on biodiversity was added in 2005 (Regeringens proposition 2005). It was reformed in 2010 (Regeringens proposition 2010; see also the overview of the NEO structure in Annex I) and now includes 16 national objectives (see figure 3 below) that are further specified as quantitative or qualitative action-oriented targets and milestones.

There is a two-way interdependency between the international level and Swedish NEOs, which the PB framework could potentially help to characterise and measure. First, global environmental change and environmental pressures originating from other countries will influence the feasibility of reaching the NEOs. The most recent evaluation of the 16 NEOs concluded that five will not be achieved due to the inability to address negative environmental pressures that go beyond Swedish borders – those relating to climate change, acidification, chemicals, eutrophication and the marine environment (Naturvårdsverket 2012a: 43). Reducing air pollution in Sweden is also identified as an area which requires international action (ibid.: 53). Figure 3 shows the relevant geographical scale for achieving the NEOs, according to the Swedish EPA.

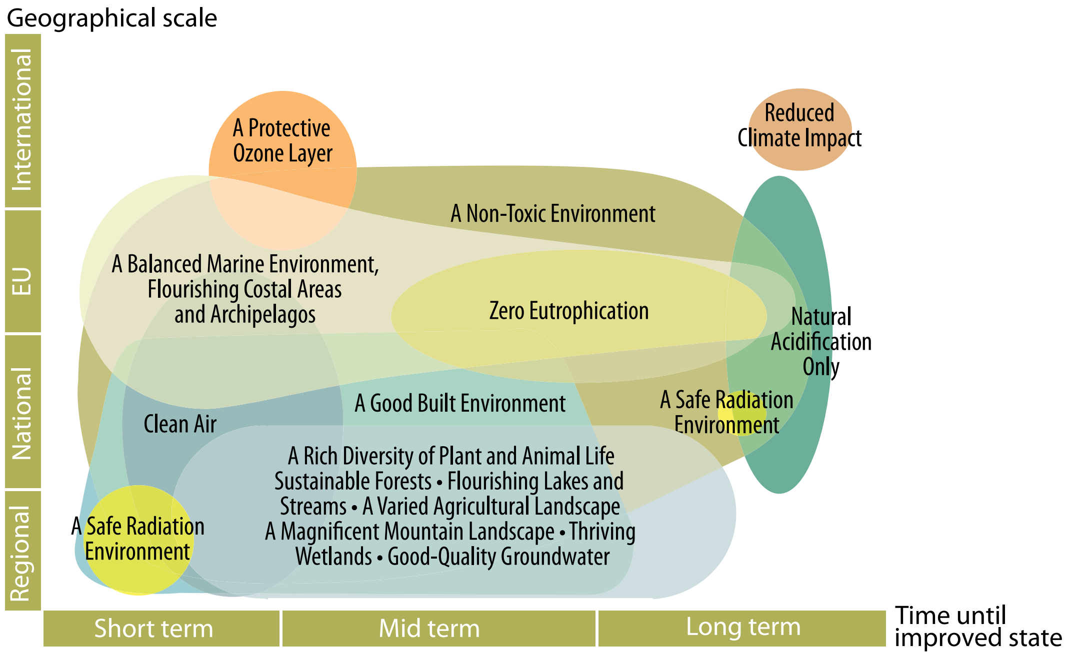

Figure 3. Relevant geographical and temporal scales for achieving the 16 NEOs
Source: Naturvårdsverket (2012a: 56), fig. 4

A set of indicators for measuring the performance of other countries on variables relevant to the NEOs could clearly inform which countries should be prioritised for Swedish cooperation, whether through bilateral programmes and diplomacy or through international cooperation. It should be noted that such cooperation would extend beyond solidarity motives for mitigating impacts in poor or vulnerable countries, as it would also be based on Swedish self-interest in achieving its NEOs. The PB framework is one possible framework for identifying such indicators.

The second form of national-international interdependency stems from the fact that Swedish production and consumption affect the global environment. The relevant policy question here is whether domestic environmental problems are being solved – and national objectives achieved – at the expense of increasing environmental and health problems beyond Swedish borders. The generational goal (see above) effectively prohibits the export of environmental problems. The question is how to monitor and evaluate that this is not happening. Applying a consumption perspective to Sweden's environmental pressures has become increasingly popular and the Swedish EPA has published several reports on this topic (Naturvårdsverket 2008; Naturvårdsverket 2010a; Naturvårdsverket 2011; Naturvårdsverket 2012bcd). So far, these studies have addressed the effects of Swedish consumption on global greenhouse gas emissions, air pollution, freshwater use, land use and, to some extent, chemical pollution. Existing tools for measuring Sweden's ecological, carbon and water footprints have been reviewed by the Swedish EPA, but were not used as indicators to assess the achievement of the generational goal in the 2012 evaluation (Naturvårdsverket 2012a). Instead, new methods are required to evaluate the generational goal, including the use of consumption perspectives.

The question is whether a list of global environmental challenges, such as the PB framework, can add value to the measurement of Sweden's and other countries' pressures on the global environment and to addressing policy questions. The Swedish EPA has identified the PB framework as a promising tool for clarifying the linkages between the NEOs, international goals and the global safe operating space (Naturvårdsverket 2010b: 69). This chapter examines whether the PBs offer a relevant and appropriate framework for achieving this.

2.2 The planetary boundaries framework: rationale and current status

Table 1 lists the nine PBs proposed in 2009, and the specific control variables selected and boundary values proposed for seven of these. The logic was first to identify key *Earth system processes*, then select appropriate *control variables* for those processes, establish at which point there is scientific support for a *threshold* (or "tipping point") effect occurring and finally propose a *boundary* value, with the precautionary principle in mind. Since 2009, new candidate boundaries have been proposed and some existing ones critiqued and/or reformulated, and the original set is currently being revised by the Stockholm Resilience Centre. A summary of the definitions under revision and general developments in the debate on PBs is provided in Annex II. The downscaling of planetary boundaries has been called for by various actors. In parallel with this report, which deals with downscaling to the national level, work is also ongoing to develop an understanding of how the crossing of thresholds at the regional scale determines the aggregate effect on global thresholds and boundaries.[5] An attempt has also been made to downscale the PBs to the national level for South Africa by linking them qualitatively to an existing set of national environmental indicators.[6]

Rather than discussing the scientific underpinning of individual boundaries in detail, we focus here on whether the underlying rationale of the PB framework fits the analytical needs in relation to the international dimension of the Swedish NEOs, as per the policy questions identified in chapter 1. We refer to other indicator sets and approaches in passing (for a fuller review of alternatives see Rockström et al. 2009b, supplementary information). What are the strengths and weaknesses of the PB framework for understanding and measuring the international dimension of the NEOs?

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[5] Ongoing research led by the University of Southampton based on Costanza et al. (2007).
[6] Ongoing research led by Megan Cole, University of Oxford.

Table 1. The nine planetary boundaries proposed by Rockström et al. (2009b)

Earth system process	Control variables	Proposed boundary	Most recent measurement
Climate change	– Atmospheric carbon dioxide concentration (parts per million by volume) – Change in radiative forcing (watts per metre squared)	350 ppm +1 W/m^2	393.81 ppm +1.87 W/m^2
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90
Stratospheric ozone depletion	Concentration of ozone (Dobson units)	276 DU	283 DU
Biogeochemical flows: nitrogen cycle and phosphorus cycle	– Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year) – Quantity of P flowing into the oceans (millions of tonnes per year)	35 Mt 11 Mt	121 Mt 8.5–9.5 Mt
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	To be determined	To be determined
Freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000 km^3	2,600 km^3
Land use change	Percentage of global land cover converted to cropland	15%	11.7%
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10 E/MSY	>100 E/MSY
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in the global environment, or the effect on ecosystem and functioning thereof	To be determined	To be determined

Sources: Rockström et al. (2009b). There are more recent measurements than in the 2009 article (see right-hand column in table) for the following PBs: for *climate change*, latest annual ppm average for 2012 (NOAA 2013) and radiative forcing in mid-2012 (NOAA 2012); for *ozone depletion* for 2009 (WMO 2010); for *land use change* for 2009 (FAO 2012) (same value as in original paper but for more recent year).

First, the fact that the PBs constitute a **scientifically based framework** – developed and peer-reviewed by scientists with the primary objective of starting a scientific debate – rather than a policy framework with politically agreed target levels can be considered both a strength and a weakness. It would be a weak framework if the *political legitimacy* of the targets/boundaries was considered important, i.e. that a critical mass of national governments had bought in to the concept and the proposed boundaries. Furthermore, it was not originally intended as an operational framework for national and international *performance measurement* or for making policy recommendations. For comparative performance measurement, an index such as the *Environmental Performance Index*[7] is more directly relevant. This index includes several indicators not just on environmental and ecological quality but on human activities and policy responses, e.g., the extent of protected areas, agricultural

[7] See http://epi.yale.edu/.

subsidies, pesticides regulation and carbon intensity per GDP – variables that governments can more directly control their performance on. In this regard, the PB framework is more similar to the definition of the 16 NEOs, in that boundaries have been defined in terms of the *state* of the Earth system or the global environment, with a view to understanding the harmful *impacts* on ecosystems and resources. This suggests that in order to connect national environmental performance with the PB framework, assumptions will be required on how human-controlled *pressures* and *drivers* are linked to changes in the state of the Earth system. Therefore, the methodology developed in chapter 3 analyses the PBs from the perspective of the commonly used Driving forces–Pressure–State–Impact–Response (DPSIR) framework for environmental indicators (see section 3.2).

On the other hand, the fact that the PB framework was developed by scientists primarily for scientific purposes can be considered a strength in that it addresses absolute performance on observed *problems*. Many policy indicators are more geared to measuring relative performance on policy targets or aspirations that may or may not match the magnitude of problems. There is thus a choice to be made between a scientific and a policy-oriented framework when selecting indicators to capture the international dimension of NEOs. It is important to be aware of the implications and limitations of each approach.

A clear strength of the PB framework is that it offers a **comprehensive and possibly exhaustive** set of non-weighted variables to capture key global environmental challenges rather than existing single-issue indicators and footprint tools. The list of nine PBs is more comprehensive than, for example, the carbon footprint as an indicator of national environmental performance.

A further strength is that it **departs from scientific knowledge about key environmental thresholds and tipping points rather than the availability of data**. The identification of the nine PBs was not based on available data. Indeed, two have not yet been quantified. Instead, the framework highlights issues that are regarded as important within science, and where there is a need to derive more data. Other indicator sets adopt more data-driven approaches, in that they measure what happens to be currently measurable. Where there are data gaps for known problems, such indicator sets risk losing relevance for characterising these problems.

Finally, it can be considered innovative and a significant strength that the PB framework not only identifies key variables or relevant indicators, but also absolute boundary values or target levels. The **setting of clear benchmarks** in this way allows measurement of the absolute performance of countries in relation to the boundary, rather than relative performance between countries only. In this way, the PB framework allows us to answer the question: ‘is the best performer performing well enough’? This in turn means that there can be prioritisation between issue areas or PBs in terms of political attention and resources, something which is not possible without absolute benchmarks.

Potential weaknesses that should be kept in mind when assessing the relevance of the PB framework to the international dimension of Swedish

NEOs relate to the issue of **spatial scale**. It is a common misconception that the PBs are all exclusively global environmental problems, and as such constitute global public goods that can only be provided through international cooperation as mediated through IEAs or other instruments (see e.g., Lewis 2012). Indeed, some are global problems (climate change, ocean acidification, stratospheric ozone), since the relevant pollutants are more or less globally well-mixed, and have led to international responses with different levels of burden-sharing agreements. This report refers to these systemic processes as being "truly global PBs". However, several of the PBs manifest themselves primarily at the local or regional levels but, when aggregated, may alter the resilience of the Earth system through the functioning of sinks and sources of carbon and by regulating water, nutrient and mineral fluxes (see figure 4). Alternatively, some forms of regional change can have global consequences through teleconnections. For example, deforestation of the Amazon basin or deoxygenating the Gulf of Mexico are regional changes that have global consequences, even if nowhere else is deforested or deoxygenated.

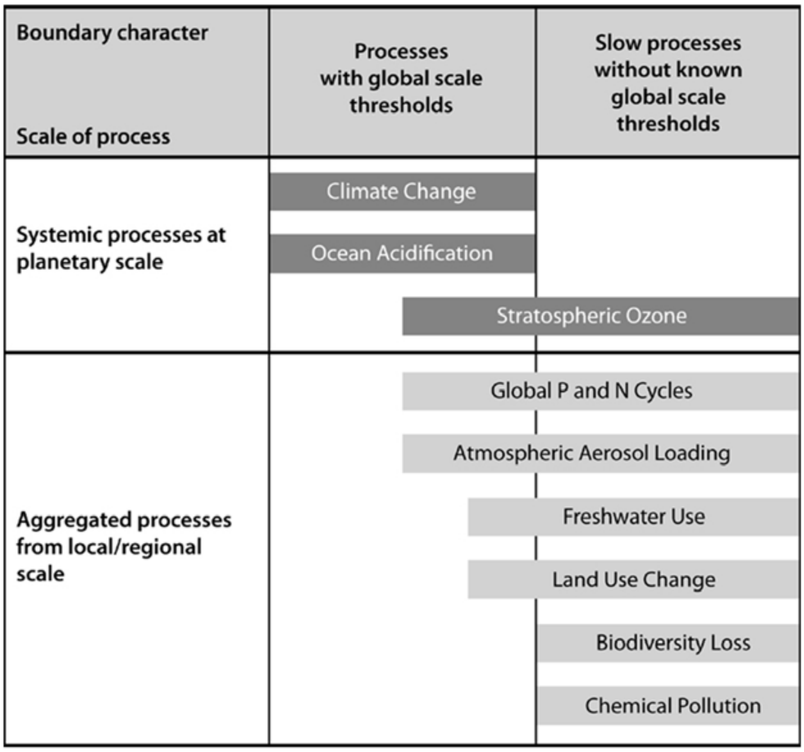

Figure 4. Categories of planetary boundaries
Source: Rockström et al. (2009b).

This difference in the type of PB has at least two implications in terms of national performance measurement. First, for the 'aggregated' PBs, it matters *where* human pressure is exerted. For a truly global PB such as climate change, every emission reduction regardless of place of origin counts equally. This means that all countries and their citizens can, in principle, have an equal responsibility and that their performance on reducing pressure can easily be compared on a per capita basis. For an 'aggregated' PB, such as land use, it matters *where* human pressure is exerted from a planetary perspective. A square kilometre of forest has greater carbon storage and biodiversity value in some places (e.g., the Amazon basin) than others (e.g., temperate forests). Such **sensitivity to place** makes comparison of national performance more complex. We discuss this issue in more detail when developing a methodology in the chapter 3. It is also clear that international cooperation through global IEAs will not be the only or even the most effective response to all PBs. It is more useful to think of them as requiring international, regional, national and local governance (Nilsson and Persson 2012).

Second, with regard to aggregated PBs, the crossing of **local and regional thresholds with direct local and regional impacts** may often be more politically salient and hence an important focus for environmental policy. Aggregation to the level of global environmental change may be perceived to be of secondary importance. Importantly, the PB framework does not identify or allow the measurement of performance on such local thresholds. However, it should be noted that local and regional environmental change could have global repercussions not only of an environmental nature. For example, regional water scarcity may cause political turbulence, which could result in international instability.

A final potential weakness could be that some of the PBs as currently formulated **do not consider quality aspects**, but primarily quantity. For example, the land use boundary which addresses the deforestation issue, as well as implications such as carbon storage, the albedo effect and biodiversity, does not allow for differentiation of whether remaining forested areas are degraded or not. The quality of management has important implications. However, many "high-level" or headline indicators suffer from the same constraint and a general solution would be to complement them with more detailed indicators that capture quality aspects.

In sum, the PB framework appears to be **generally relevant** to understanding and measuring the international dimension of Swedish NEOs. The next question is whether the PBs are also specifically relevant to individual NEOs, i.e. whether there is a good match between the two sets of objectives and indicators. This question tackled in the section below. The key *strengths* of the PB framework compared with alternative indicator sets are its comprehensiveness, that it is not data-driven and that absolute benchmarks are provided. The key *weaknesses* of a lack of spatial differentiation and an inability to consider quality aspects are to some extent shared with other indicator sets and could be overcome by complementing the PBs with more detailed and disaggregated indicators. When it comes to PBs being a scientifically proposed framework rather than a policy framework and the fact that local environmental thresholds and impact may matter in their own right, these are strategic choices related to the needs of decision makers. Consequently, these choices need to be made by the decision maker and the potential user of the PB framework – in this case, the Swedish EPA.

Finally, in spite of this general relevance, two key uncertainties around the framework should nonetheless be recognised. The PB framework builds on increasing scientific knowledge about **non-linear dynamics and threshold effects with possible irreversible outcomes** (Scheffer et al. 2001; Folke et al. 2004; Biggs et al. 2009). The original scientific articles on PB strongly highlighted that there is considerable uncertainty around where the thresholds are situated along the control variables. The definition of specific boundaries was a first attempt to estimate a safe distance from thresholds and the precautionary principle was invoked. In parallel, great uncertainty surrounds the environmental and socio-economic effects of crossing these thresholds. As the scientific evidence improves, the PB definitions are likely to be revised over time, something which any policy applications or uses should consider and prepare for.

Furthermore, a special source of uncertainty and reason why boundaries may be redefined is the high number and significance of **interactions between PBs**, which was also emphasised in the 2009 articles. It was not feasible to model or analyse these interactions in a detailed way at the time, but new modelling efforts have recently been initiated. One example of an interaction is that climate change (induced by transgressing the climate change PB) could lead to drier conditions, which would reduce the area of land available for agriculture and therefore put additional pressure on the land use PB (Rockström et al. 2009b). This means that the current PBs are set as "gross boundaries", whereas "net boundaries" would have taken account of such interactions and probably have been set at even more precautionary levels. According to Rockström et al. (2009b: 32), "[t]his suggests the need for extreme caution in approaching or transgressing any individual planetary boundaries". In terms of relevance for national performance measurement, the current PB framework should not be seen as a fixed set of boundaries and may need adjustment as interactions are better understood.

2.3 Linking Sweden's national environmental objectives with the planetary boundaries

Having established the general relevance of the PB framework to the system of Swedish NEOs, the question arises whether they are thematically matched, or whether they address similar problems. To what extent would it be possible to draw conclusions in relation to each individual NEO, given the international environmental pressures captured by indicators based on the PB framework?

Figure 5 shows the thematic matching identified in this report. Solid lines between PBs and NEOs represent direct matches, dashed lines represent indirect or limited matches and dotted lines represent weak matching. Note that this comparison is made between the scope of the boundaries/objectives and how they are formulated, not their causal interlinkages. If the linking exercise were about identifying drivers, many more arrows could be expected.

For example, the NEO Zero Eutrophication is a driver behind many of the ecosystem/landscape NEOs (numbered 8 to 14).

We identify clear and direct links between PBs and five of the NEOs:; *Reduced Climate Impact* (1), a *Non-Toxic Environment* (4), a *Protective Ozone Layer* (5), *Zero Eutrophication* (7), and a *Rich Diversity of Plant and Animal Life* (16) (see Figure 5). The first four of these NEOs are also among the five identified by the Swedish EPA for which Sweden has only limited capacity and legal competence to achieve the national objective (see section 2.1). The match for *Zero Eutrophication* is even stronger if the new proposed PB for phosphorus is considered (see Annex II). Note that a PB for chemical pollution has yet to be defined, so it is not yet clear how well it will match with aspirations and targets under the NEO a *Non-toxic Environment*.

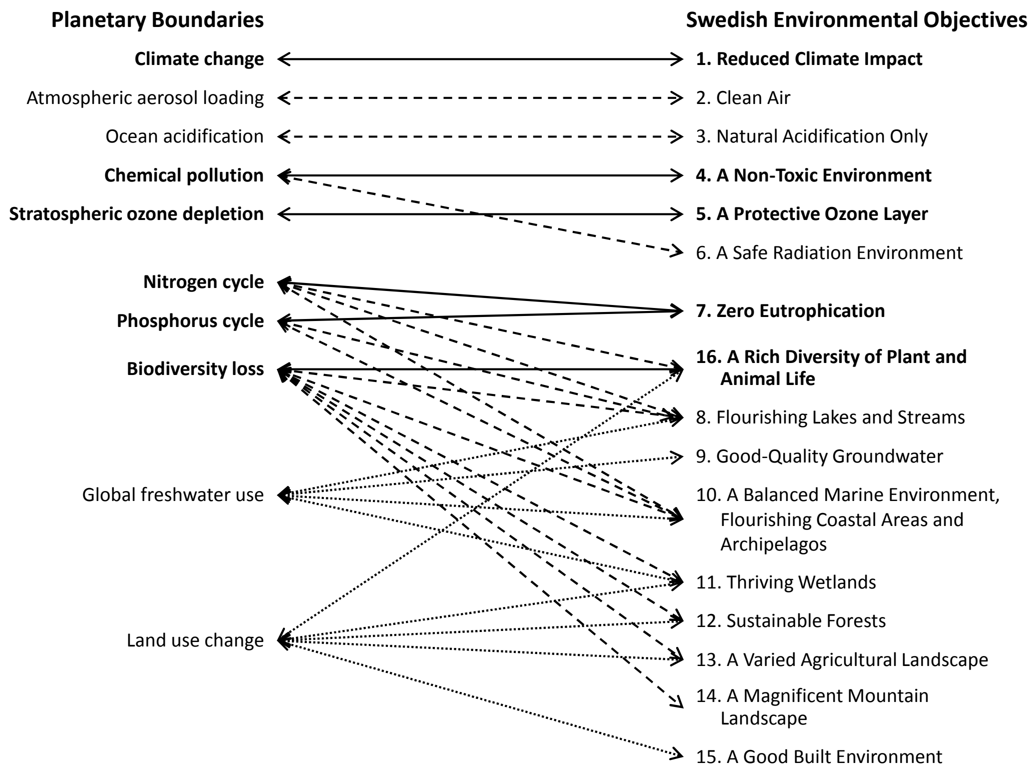

Figure 5. Thematic matching of NEOs and PBs

For a further three NEOs, there are matching PBs of only limited or indirect relevance. Depending on its future formulation and quantification, the PB for chemical pollution may or may not address *A Safe Radiation Environment* (6). *Clean Air* (2) may also be partially matched by the PB for atmospheric aerosols, but the latter is currently only formulated to include particulates and not other air pollutants and has furthermore not yet been quantified. (The NEO also covers benzene, ground-level ozone and nitrogen dioxides.) *Natural Acidification Only* (3) is partly matched by the PB for ocean acidification, but the latter omits acidification of freshwaters and there is no PB covering long-range acidifying air pollutants (sulphur dioxide and nitrous oxides).

NEOs 8–14 refer to the desired states of particular ecosystems and/or landscapes, and are therefore not well matched with the PB logic. However, biodiversity is a key aspect of many of these NEOs, and they are thus partly addressed by the PB on biodiversity loss. Note that only one of these NEOs is seen as subject to international environmental pressures by the Swedish EPA, *A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos* (10). This NEO, however, is partly addressed by the PBs for the nitrogen and phosphorus cycles.

Finally, two PBs appear not to be core concerns in any of the NEOs: *global freshwater use* and *land use change*. While there is a thematic link with the ecosystem/landscape type NEOs, the logic on which they are based does not appear to permeate the system of NEOs. Sweden is a water- and forest-rich country. Water-related NEOs address water quality rather than water consumption and scarcity. Land use change may be somewhat addressed through conservation and biodiversity, but not in terms of carbon storage, the albedo effect or land conversion. However, as Swedish consumption influences freshwater use and land use change globally (Naturvårdsverket 2010a; Naturvårdsverket 2010b), there is a strong link between these PBs and the generational goal.

This analysis shows that **the match between Sweden's NEOs and the PB framework is good, but not perfect**. Many environmental problems of national concern in Sweden are clearly also of global concern, and global concerns have their local manifestations in Swedish objectives. The PBs are thus relevant to Swedish environmental policy also at the level of individual NEOs.

2.4 Summary

It is indeed relevant to better understand the links between the national and international levels, both in a general sense and when considering specific NEOs. There is a good but not perfect match between the PBs and the NEOs. This means that the PBs may be appropriate for assessing Swedish performance on the generational goal, and can to some extent be used to understand the of Sweden's competence deficit in relation to its NEOs.

However, some caveats should be kept in mind when exploring appropriate methodologies for measuring national performance. There is considerable uncertainty around several PBs, related to threshold behaviour and to the interactions between PBs. Any performance measurement should therefore recognise that the absolute benchmarks or the boundary values, and the control variables may change, subject to the availability of better scientific evidence. Furthermore, several PBs are place-sensitive in that it matters where human pressure is exerted and/or a boundary is transgressed. Comparing national performance may not make sense for such PBs and the planetary boundary cannot easily be downscaled to the national or per capita levels.

3 Developing a methodology

So far, the nine PBs have not been downscaled to national boundaries or targets, or indeed to the regional or local levels. Nor have nationally relevant indicators been formally linked to PBs. This report pioneers the development of such a performance measurement framework. However, a simple translation to the national scale is not possible for several PBs if the original definitions are strictly adhered to, which we choose to do in this report, and two boundaries have yet to be quantified (*chemical pollution* and *atmospheric aerosol loading*). In consequence, this report suggests quantified national boundaries and indicators for measuring national performance on only four downscaled PBs: *climate change*, the *nitrogen cycle*, *Land use* and *Water use*. For the remaining PBs, it will be significantly more challenging to downscale them meaningfully to the national level. For example, it is not easy to disaggregate the aggregated boundaries (see Figure 4), nor to create policy relevant indicators. Nonetheless, we suggest relevant alternative indicators that could be used to compare relative national performance for all the remaining PBs apart from *atmospheric aerosol loading* and *climate change* (see Figure 6).

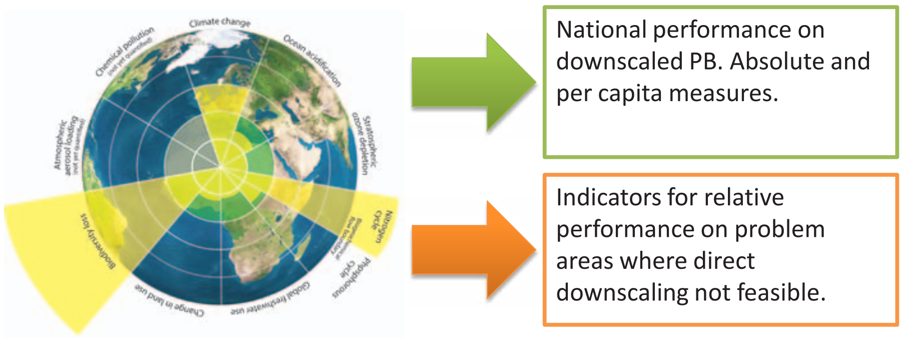

Figure 6. Types of indicators developed in this report

This chapter discusses some general considerations to be taken into account when downscaling boundaries and/or identifying indicators. Chapter 4 describes the methodology for each individual PB and reports the results.

3.1 Understanding national performance

In this report, national performance means performance on such parameters that countries and human actors can directly *control*, such as emissions of pollutants or conversion of land, rather than the state of the environment (e.g., state of ocean acidification or amount of stratospheric ozone). One of the main challenges with the PB framework is that it includes a mix of boundaries defined as states of the environment and as pressures driven by human activities. Another challenge is that some boundaries are truly global whereas others are aggregated local or regional processes that result in global effects (see Figure 4). In order to discuss national performance, therefore, each boundary needs to be individually reviewed, and a methodology developed that translates the global boundary into a national counterpart while maintaining a clear link to the original problem definition.

3.2 Mapping states, pressures and drivers: clarifying causality and interlinkages through DPSIR

In order to identify indicators that can indeed be controlled and where national performance can be measured, there is a need to establish more clearly the causal chains associated with each boundary; what human behaviour causes us to transgress a certain boundary? We used the DPSIR framework, which is commonly used for environmental indicators. Our assumption is that humans, stimulated by policies or not, can only directly control or change *drivers* (D) (e.g., transport use or fixation of nitrogen from the atmosphere) or *pressures* (P) (e.g., GHG emissions, or the release of nitrogen into the biosphere) of environmental change, but not *states* (S) (e.g., atmospheric GHG concentration) or *impacts* (I) (e.g., temperature change, crossing ecological thresholds, increased water scarcity, etc.). In the PB framework, for various reasons, the nine PBs identified were not all defined in the same DPSIR category. Instead, one is a driver.[8] Some are states, and biodiversity loss can be seen as an impact following on from changes in states. Mapping the relevant casual chains is an important exercise for developing a methodology for measuring national performance on PBs. The analysis makes it clear what is being measured and the extent to which that parameter can be controlled by relevant decision makers at the national scale. Figure 7 provides a first illustration of causal chains for PBs according to the DPSIR scheme. Note that there are multiple stages of both drivers (fundamental vs. proximate) and impacts (first-, second-, third-order impacts, and so on).

Mapping out relevant causal chains according to the DPSIR framework is also useful given that some of the PBs have the same drivers and pressures, e.g., ocean acidification and climate change are both caused by anthropogenic GHG emissions. It also illustrates that some are causally linked, e.g., the conversion of forest to cropland (PB on land use) may degrade habitats, which may lead to species extinction (PB on biodiversity loss). This suggests where common indicators can be used to indicate performance on several PBs. Identifying interlinkages in this way will also highlight which drivers and pressures controlled by humans are the key ones to act on in order to prevent or reduce the transgression of multiple boundaries. Furthermore, the impacts

[8] The control variable in the original PB framework for measuring the N-cycle is fixation of nitrogen from the atmosphere, which is a driver of fertiliser use (pressure) which leads to changes in nutrient status and impacts such as eutrophication.

resulting from the transgression of some PBs can influence others, as is illustrated for *Climate Change* in figure 7. Addressing complexities in this way will further highlight that each boundary should not be addressed using its own set of separate agreements, institutions and policies.

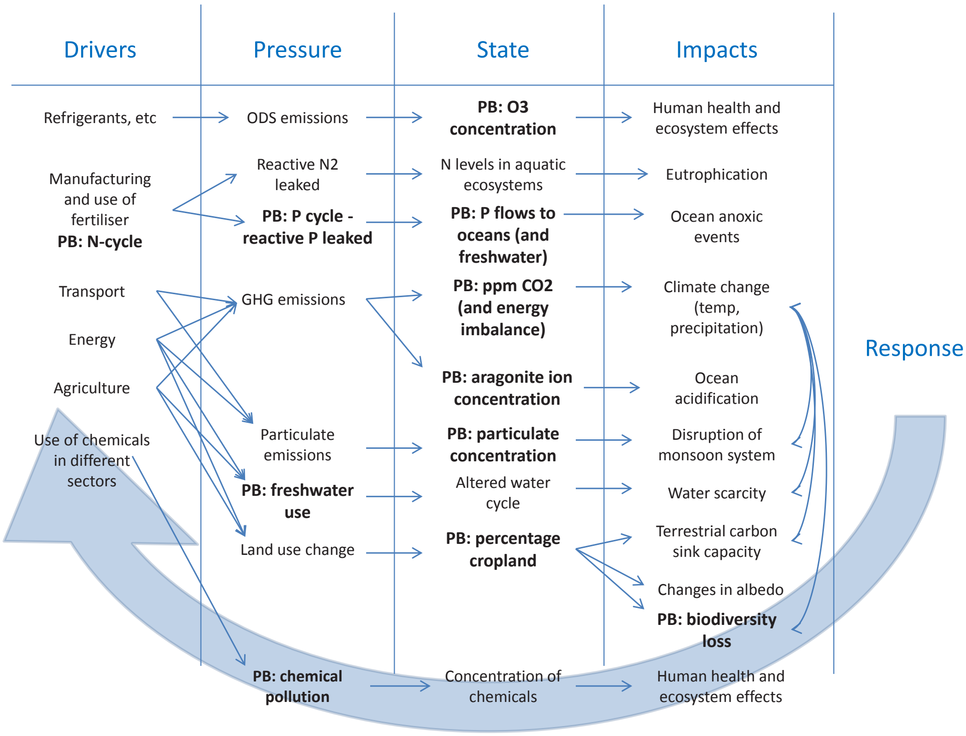

Figure 7. Analysing planetary boundaries in a DPSIR framework

One implication of measuring national performance is that proxy indicators will sometimes have to be used. In the original PB framework there are three systemic processes at the planetary scale that are represented by globally well mixed *state* variables not under the direct control of countries: *climate change*, measured in average carbon dioxide (CO_2) concentrations; *stratospheric ozone depletion*, measured in the thickness of the ozone layer; and *Ocean Acidification*, measured as the saturation state of aragonite in surface sea water (Rockström et al. 2009). For these variables, the methodological choice made in this report is to convert the global PB state variable to a corresponding pressure in terms of emissions of CO_2 and ozone depleting substances (ODS) at the national scale. However, due to the change in control variable from state to pressure, each proposed threshold (the actual boundary) needs to be reinterpreted to enable an assessment of national performance against the proposed boundaries. That is, the change from CO_2 concentrations in parts per million (ppm) to tonnes of CO_2 (tCO_2) emitted requires a new boundary definition that corresponds to the original 350 ppm boundary. As is noted in figure 7, we further assume that ocean acidification is captured by measuring CO_2 emissions and no other specific indicator is proposed.

3.3 Top-down downscaling of boundaries vs. locally and regionally specific boundaries

The majority of the original PBs were conceived as aggregate effects from locally heterogeneous environmental states or pressures. These are the *N and P cycles*, *atmospheric aerosol loading*, *freshwater use*, *land use change*, *Rate of biodiversity Loss*, and *Chemical Pollution* (see Figure 4). In the PB framework these processes are included due to aggregated effects at the planetary scale. Control variables were thus defined as aggregated states or drivers at the global level, e.g., the global sum of all nitrogen fixation (driver), global emissions of phosphorus to oceans (pressure) or global land use (state) (Rockström, Steffen et al. 2009).

For two of these aggregated PBs (*freshwater use* and *land use change*), we suggest how the original PB threshold can be interpreted as a nationally aggregated threshold. Available water resources depend on local or regional conditions at the scale of the water catchment. Similarly, land use change occurs at the local or regional scale and its impact depends on available land (Rockström, Steffen et al. 2009). The method we adopted is to aggregate available freshwater and land resources to the national level instead of the global. The method is thus directly comparable with that applied in the original paper but applied to a different scale. This approach has severe limitations as water and land use have different threshold effects in different types of ecosystems. To identify the actual local and regional boundaries based on thresholds in ecosystem is an important task, but it is not the primary purpose of this report.

3.4 Different types of comparisons: Absolute vs. per capita performance of countries

For as many PBs as possible, we report both the absolute performance of countries and their per capita performance. Absolute performance is important for identifying the currently most significant polluting countries. Per capita performance, on the other hand, is needed to ensure sensitivity to equity concerns and rights to development. Different approaches to bilateral cooperation could be used for countries with high absolute performance (e.g., technical assistance, technology transfer, policy development) and for those with rapidly changing per capita performance (e.g., consumer awareness, lifestyle changes).

To obtain both measures, we downscaled boundaries where feasible to *per capita* boundaries, as this enables a comparison of countries regardless of size.

Multiplying these by national population then provides national, *absolute* boundaries. National performance, however, is generally presented as a per capita measure. Note that the methodology does not include any consideration of fairness or equity in the distribution of resources or emission rights, i.e., there are no differentiated per capita boundaries according to fairness concerns. Various frameworks have been developed particularly in the field of GHG emissions that recognise and incorporate factors such as historical emissions or capacity to pay when assigning different "burdens" or boundaries to countries.[9] Such an analysis is beyond the scope of this report.

For two boundaries, *freshwater use* and *Land use Change*, the nature of the global PBs allows a different calculation of national absolute boundaries and performance. Since they specify a national extraction rate and state of land use change, this can be applied to the specific national resource base (freshwater availability and land availability) and a *country-dependent* absolute boundary can be obtained.

Figure 8 describes the methodology developed, with this dimension of absolute vs. per capita performance as one of the key aspects. It is important to remember that all the per capita boundaries presented are moving targets. As the world population increases or decreases, per capita boundaries will change as the safe space needs to be shared by more individuals.

3.5 Different approaches to the per capita performance of countries

This report differentiates between territorial and consumptive performance. These are further explained below.

3.5.1 Territorial performance

Territorial performance refers to net emissions or resource use that occur within the territory of the country, e.g., emissions of CO_2 or the use of nitrogen or ODS. These are often also referred to as production (Peters et al. 2011). The approach is equivalent to how annual territorial CO_2 emissions are currently reported to the UNFCCC in the national inventory submissions.[10] If a country extracts fossil fuels or fixates nitrogen but exports the fuels or nitrogen, this is not included in the submission. For each boundary, the methodological approach is to identify a relevant performance indicator in terms of annual emissions or resource use within the national territory that contributes to the transgression of each PB. Territorial measures are readily available for a number of the process variables used in the PB framework.

[9] E.g., the Greenhouse Development Rights framework and the Contraction and Convergence model.
[10] See http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php

3.5.2 Consumption performance

One of the aims of this report is to assess Sweden's contribution to environmental problems beyond its borders (the generational goal) and the methodology developed should therefore capture the global impact of Swedish consumption. In contrast to territorial performance, consumptive performance traces the origin of emissions or resource use through supply chains – typically through input-output analysis – and attributes the emissions or resource use of a country to the consumption of its citizens. As is mentioned above, the Swedish EPA has initiated a work programme in this area (see (Naturvårdsverket 2010ac). Scientific research into consumption perspectives is making rapid advances, not only on refining the measurement of carbon footprints (Paul et al. 2010; Raudsepp-Hearne et al. 2010; Berglund 2011) but also on developing new methodologies for estimating nitrogen (Leach et al., 2012), water (Hoekstra and Mekonnen 2011), land use (Lugschitz et al. 2011) and biodiversity footprints (Lenzen et al. 2012; Raffaelli et al. 2012).

Consumption-based measures are the most direct method of discussing Sweden's, or any other country's, impact at the planetary scale. Note that a production vs. consumption focus could also have implications for the nature of bilateral cooperation. For example, if a country performs badly on territorial measures, it could be relevant to address production technologies or a diversification of exports. If a country performs badly on consumption measures, it could be relevant to address consumer awareness and lifestyle issues.

Tools exist for assessing footprints of consumption for several of the PBs (i.e., embedded emissions or resource use in net imports), including: carbon footprints, water footprints, land use footprints and more recently biodiversity and nitrogen footprints. The methodological maturity of each of these variables varies (Naturvårdsverket 2010a), but whenever consumption-based methods are available these are included in the analysis.

3.6 Summary

This chapter presents a methodology in terms of a conceptual framework for downscaling boundaries and identifying indicators and data series. Several dimensions were highlighted: the need to convert state- and impact- variables to pressure variables in order to measure performance; the difference between truly global boundaries and those aggregated boundaries where local and regional thresholds matter; the difference between absolute and per capita measures; and the difference between territorial and consumption perspectives.

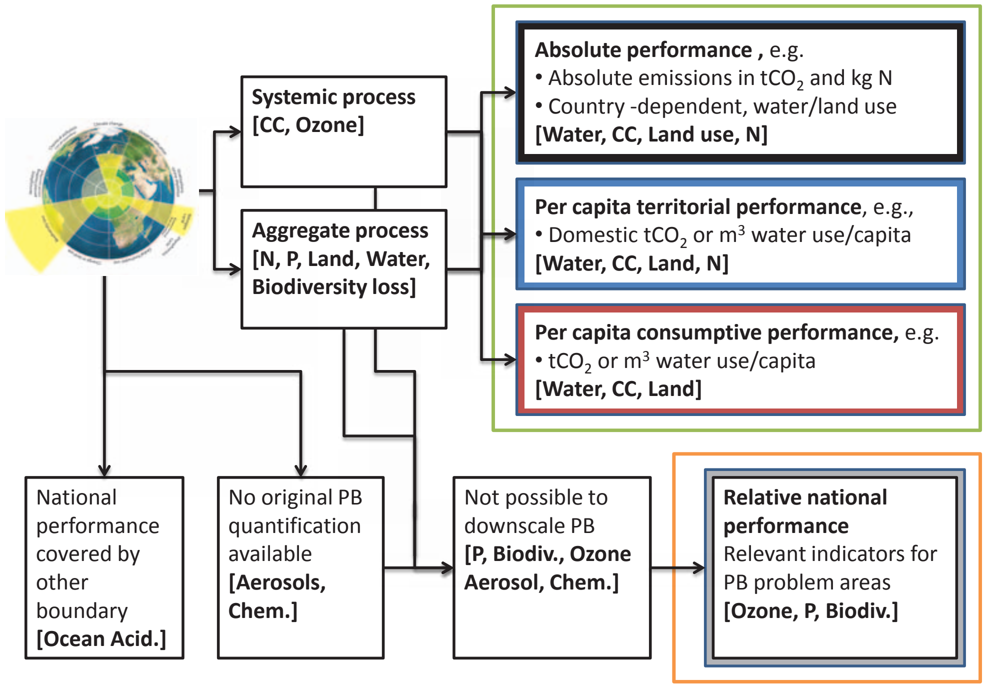

Figure 8. Methodological approach to illustrating national performance

4 Results on national performance

This chapter describes how planetary-level boundaries have been downscaled (or not) and identifies appropriate datasets. Section 4.1 describes those boundaries where we suggest that top-down downscaling is currently possible and we can therefore propose national boundaries – both absolute and per capita. Section 4.2 we describes how indicators can be used for PBs, where downscaling to national level boundaries is not possible and indicators other than the original control variables have to be identified. Country results are presented for each PB. Chapter 5 uses the results gained here to discuss the policy questions identified in chapter 1. Section 4.3 contains some reflections on boundaries where, for different reasons, it was not possible to suggest indicators.

The countries for which results are reported below were chosen by the Swedish EPA. These countries (where data is available) are:

- members of the Arctic Council;
- current partners in Swedish EPA bilateral collaboration;
- emerging economies globally (Brazil, the Russian Federation, India, Indonesia and China, the BRIICs) and in Europe (Turkey and Poland);
- categorised in Swedish development aid categories 1 and 3;[11] and/or
- OECD members.

Note that this selection of countries does not necessarily include the best or worst performers.

4.1 Downscaled boundaries and indicators for measuring direct national performance

This section outlines the methodologies for those PBs where direct downscaling to national boundaries is possible: climate change, the nitrogen cycle, land use change and freshwater use (see Figure 8). Per capita boundaries, where calculated, are based on the world population in 2010 (UN, 2012). In all graphs, the boundary is at the upper point of the green areas, which represent the safe space (see also Figure 1). All these targets will need to be updated in the future to reflect the changing world population.

4.1.1 Climate change

The PB for *climate change* was proposed as a maximum 350 ppm concentration of atmospheric CO_2 (see Table 1). To downscale this truly global variable,

[11] Category 1 is "countries with which Sweden should undertake long-term development cooperation" and category 3 is "countries in Eastern Europe with which Sweden should undertake reform cooperation", see http://www.sida.se/Svenska/Bistand--utveckling/Detta-ar-svenskt-bistand/Sveriges-bistandslander/

we assume that it corresponds to limiting warming to no more than 2°C above the preindustrial level. This is in line with the latest IPCC assessment (IPCC 2007a: 67), where 350 ppm CO_2 corresponds roughly to a 2°C warming above preindustrial levels and about 450 ppm CO_2-equivalent (CO_2eq) (IPCC 2007b: 826).[12] The next step is to associate the temperature target with a global carbon budget that can be translated into country or per capita emissions.

Identifying a per capita CO_2 emission boundary is difficult and depends on the assumptions made on the long term emission profiles and future population of the world. UNEP has concluded that a 21st century carbon budget of 1456 Gt CO_2 would result in a lower than 2°C warming at 450 CO_2eq. At the time of this analysis in 2007, this global carbon budget would correspond to annual emissions of 14.5 Gt CO_2/y, and per capita emissions of no more than 2 tonnes CO_2/y (Meinshausen 2007, UNDP 2007). More recent analysis by UNEP (2012) conclude that a 2°C target requires 21 GtCO_2eq/y in 2050, and assuming that 76% of these are CO_2 emissions (current mix) give a similar budget of 16 GtCO_2/y.

With current population of 7 billion people, we conclude that 2 tonnes CO_2/y suggested by UNDP is a good per capita boundary, but if the world population grows to 10 billion, the target need to be reduced to 1.5 tonnes CO_2/y. As it has been suggested that a more stringent target of 400ppm CO2eq might be required to stay below 2°C (See footnote 12), if anything, the boundary likely needs to be lower.

Table 2 describes the downscaled boundaries and data series selected. Based on this per capita boundary, we can derive national absolute boundaries by multiplying by population. We use the same per capita boundary for both territorial and consumptive performance.

Table 2. Options for downscaling the climate change boundary

Planetary Boundary	**Per capita (current population)**		**Absolute**	
Climate Change	Territorial performance	Consumptive performance	Per capita * national population	Country-dependent (relative to national resource base)
Unit and data set	**t CO_2 / capita / y** *CDIAC (2012)*	**t CO_2 / capita / y** *Peters et al. (2011)*	**t CO_2 / y** (territorial or consumptive)	n/a
National boundary	**2 t CO_2 / capita / y** *UNDP (2007)*		**Eg., Sweden: 18 Mt CO_2 / y**	n/a

[12] The PB for climate change specifies an upper boundary of 350 ppm CO2. According to the IPCC (2007a: 67, table 5.1), stabilisation scenarios at 350–400 ppm CO2 correspond to 445–490 ppm CO2eq which results in a global average temperature increase of 2.0–2.4 degrees. The PB is thus comparable in level of ambition to the existing 2 degree target. However, these calculations are based on probabilities. Given the uncertainty in climate sensitivity, to achieve a higher probability of achieving the 2 degree target than the 450 ppm CO2eq target (UNDP 2007), 400 ppm CO2eq would be more appropriate. For example, the Scientific Council for Climate, which advised the Swedish government on climate policy in 2007, argues that the 400 ppm CO2eq is more appropriate (Miljövårdsberedningen 2007).

It is important to recognise that there are number of caveats to this analysis. The most important one is that a blunt and uniform 2 t CO_2/capita boundary does not take into account the difficulties of achieving a cost-effective and fair burden sharing.[13]

Data for measuring national territorial performance are available for all countries in the world. Figure 9 shows data from the Carbon Dioxide Information Analysis Center (CDIAC) (blue bars). Data is not as readily available for a consumption-based estimate of national performance, and the use of different methodologies makes comparisons between studies of an individual country difficult. The most complete study to date is Peters et al. (2011), and figure 9 includes data from this study (the red bars). Note in particular that the Peters et al. dataset gives a lower estimate for Swedish consumption than several other studies (see Naturvårdsverket 2010bc; Naturvårdsverket 2012b).

Figure 9 shows that few countries currently operate within the per capita boundary for *Climate Change*. It is also the case that all the countries below the boundary are countries that can be expected to increase their per capita emissions?. Although development is in theory not associated with higher emissions, few countries in the word can show a genuine decoupling of emissions and economic development, and less developed countries thus of necessity have a right to emit more CO_2 than they currently do if they have the right to develop (Baer et al. 2008). A somewhat surprising result is that for many countries the difference between territorial and consumptive emissions per capita is smaller than the amount by which the boundary is exceeded. In other words, country performance in relation to the downscaled PB is often of the same order of magnitude, whether measured in territorial or consumptive terms. Generally, the biggest difference between the two methodologies is for countries like Sweden, which have higher levels of imports and exports in relation to its total economy. Finally, these results can be compared with the absolute territorial performance of countries (emissions in Mt CO_2) presented in Figure 10. In this figure, the boundary is at the op of each green bar, and the bar itself represents the safe space. Considering figures 9 and 10 together reveals the entrenched equity problems related to climate change, in that countries like India and Indonesia, for example, are among the top 15 absolute emitters of CO_2 but still below the per capita boundary.

Overall, despite the problems with converting the measure of atmospheric concentration to a measure of annual per capita emissions, this PB is one of the more robust in terms of data availability and the scientific consensus around boundary levels. We conclude that that a per capita boundary of 2tCO_2/capita combined with an indicator on consumptive CO_2 emissions is a good estimate of national performance on the PB on climate change.

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[13] Furthermore, as the downscaled boundary is given by a per capita share of the remaining carbon budget, the 2 t / capita needs to be lower if we spend this budget faster than expected, and would need to decrease to virtually zero beyond 2050.

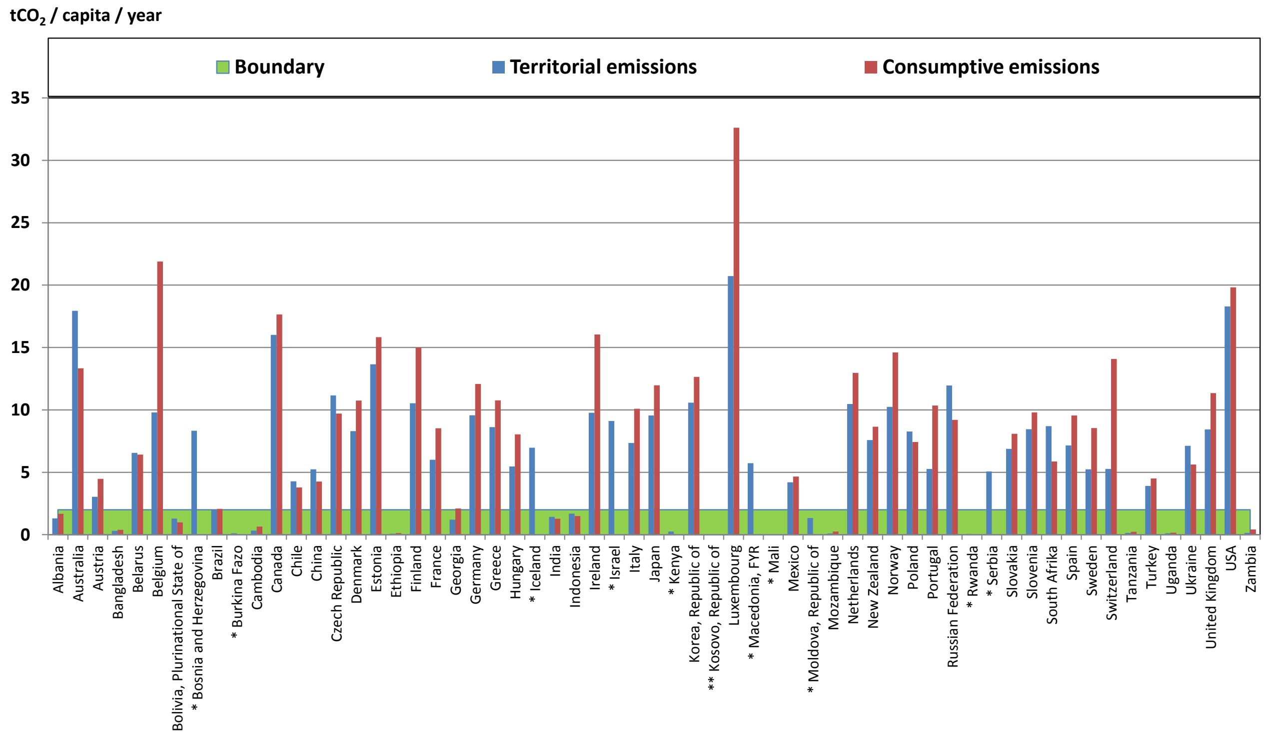

Figure 9. Climate change per capita boundary performance in 2008

Data source: CDIAC (2012) (territorial) and Peters et al. (2011) (consumptive).

Notes: Most recent data from 2008. ** No data for Kosovo *No data on consumptive performance for Bosnia-Hercegovina, Burkina Faso, Iceland, Israel, Kenya, Macedonia, Mali, Moldova, Rwanda, and Serbia.

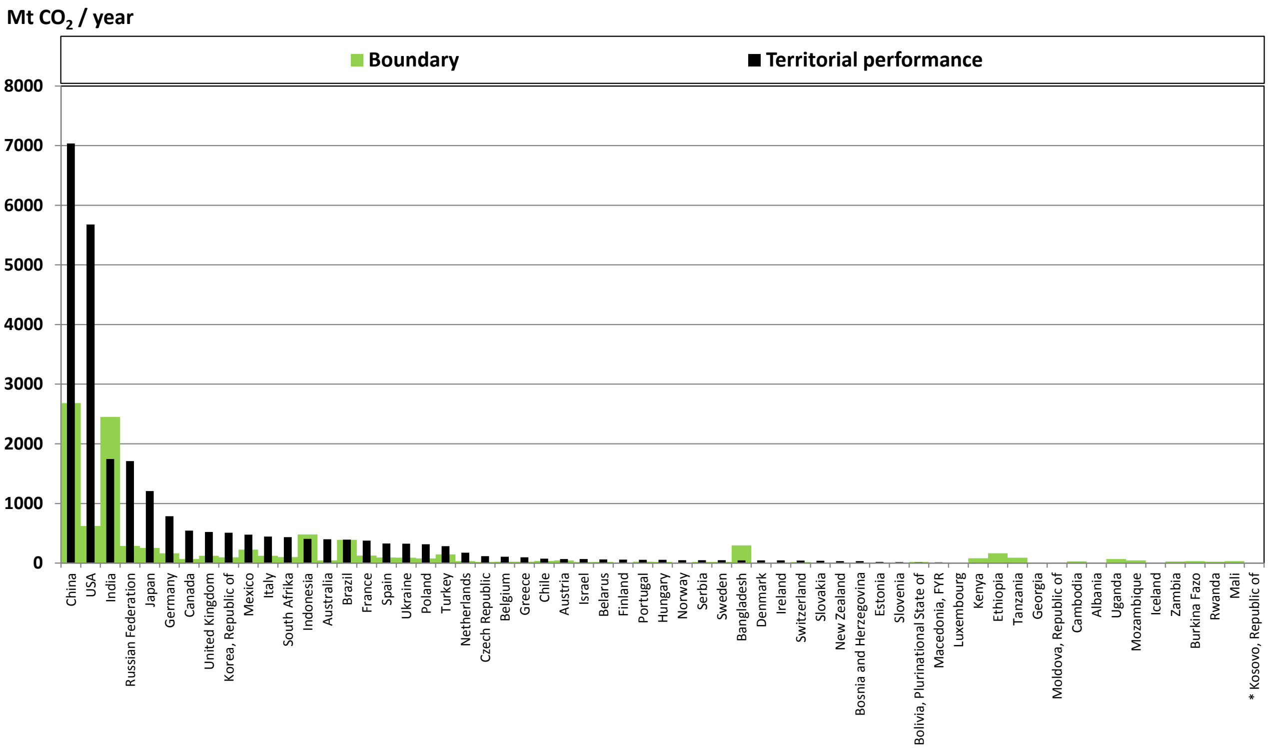

Figure 10. Climate change: absolute performance on territorial emissions, 2008

Data source: CDIAC (2012), most recent data from year 2008. *No data for Kosovo. Note that the boundary in this graph is represented by the high point of the green bars.

4.1.2 Nitrogen cycle

The original *nitrogen cycle* PB was defined in terms of nitrogen fixation, which occurs during the production of industrial fertiliser and the cultivation of leguminous crops. Excessive use of fixated nitrogen disturbs the global nitrogen cycle leading to eutrophication as a major effect. The PB was defined as a maximum removal of N_2 from the atmosphere but linked only to the industrial production of fertiliser, and set at 35 Mt per year or 25% of what is naturally fixated without human influence. This current level of 121 Mt per year far exceeds this. In order to downscale this boundary, it must be translated from a driver in terms of the production of N_2 in fertilisers to a second order driver in terms of the actual use of nitrogen. Fixation of nitrogen as part of the industrial production of fertiliser is concentrated in the few countries which happen to have an exporting fertiliser industry. We translate this to countries' net territorial use of nitrogen, i.e., the nitrogen content of the fertiliser used. Such data is recorded by FAO and available for all the countries of the world. A per capita boundary can be derived by dividing the planetary-level boundary of 35 Mt per year by the 2010 world population, giving 5 kg nitrogen per year (Table 3). This boundary also enables the calculation of countries' absolute boundaries.

Table 3. Options for downscaling the nitrogen cycle boundary

Planetary Boundary	**Per capita (current population)**		**Absolute**	
Nitrogen cycle	Territorial performance	Consumptive performance	Per capita * national population	Country-dependent (relative to national resource base)
Unit and data set	**kg N / capita / y** *FAO (2009)*	**kg N / capita / y** *Leach et al. (2012)*	**t N / y** (territorial or consumptive)	Not yet quantified, but a suggestion is WPL, Liu et al. (2012)
National boundary	**5 kg N / capita / y** *Rockström et al. (2009) divided by world population*		**Eg., Sweden:** **45,000 t N / y**	Not yet quantified, but suggestion is WPL<1

Country-dependent boundaries have not yet been defined but one option worth considering is the Water Pollution Level (WPL) for dissolved nitrogen. This indicator traces the amount of reactive nitrogen in watersheds in relation to allowable nitrogen concentrations before water becomes that polluted. Global estimates of this measure are available for the 300 largest global watersheds (Liu et al. 2012).

Figure 11 shows territorial performance against the 5 kg per capita per year nitrogen boundary. As with the climate change PB, few countries are below the per capita boundary for nitrogen. Many of the countries below the boundary are developing countries for which the affordability of fertiliser may be an issue, but there are also other trends that can be explained by the size and type of agricultural production systems in countries and by soil quality. Per capita performance can be contrasted with the absolute territorial performance of countries shown in Figure 12, which shows the countries that use the most nitrogen in absolute terms. (Note that in this figure the boundary corresponds to the high point of the green bars). As expected, the world largest countries and countries with large agricultural sectors dominate the global use of nitrogen fertiliser.

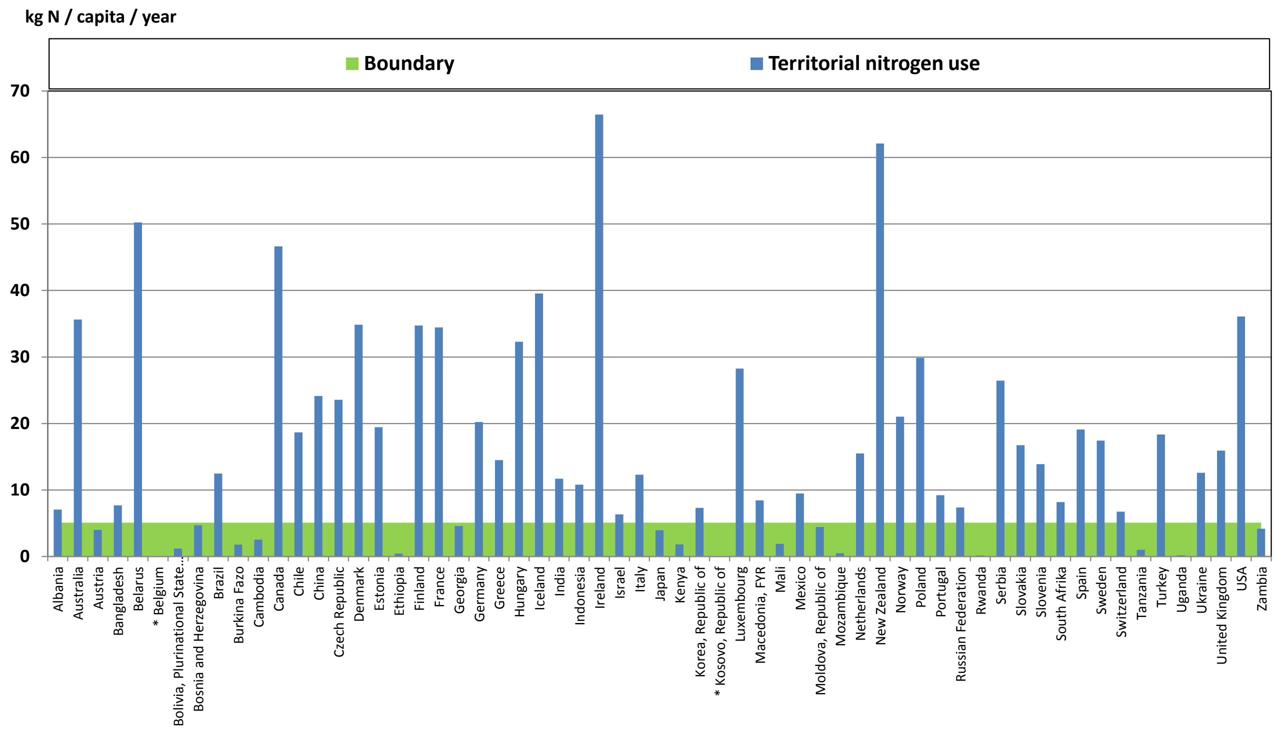

Figure 11. Nitrogen: territorial performance on per capita boundary, average of 2005–2009
Data source: FAO (2012), an average of 2005–2009 is used due to the variability of the data.
*No data for Kosovo and Belgium.

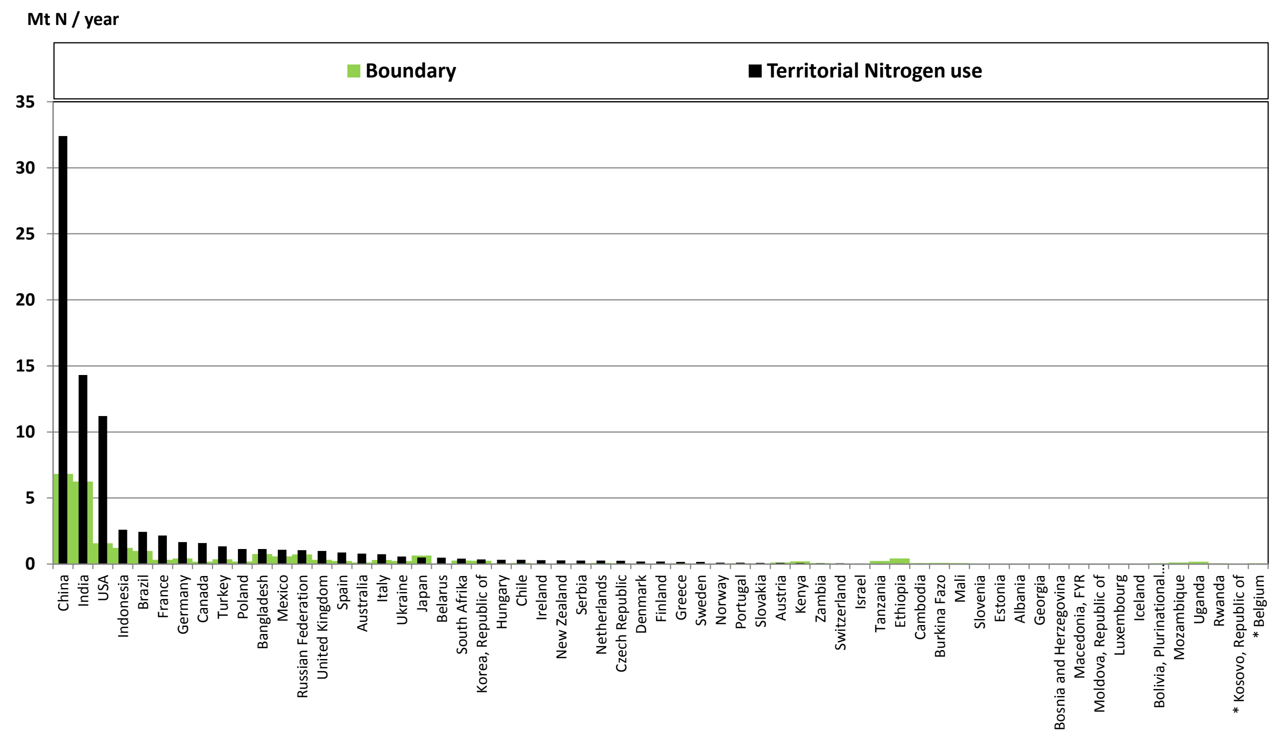

Figure 12. Nitrogen: absolute performance on territorial nitrogen use, average of 2005–2009
Data source: FAO (2012), average of 2005–2009 used due to the variability of the data.
*No data for Kosovo and Belgium. Note that the boundary in this figure is represented by the high point of the green bars.

A number of limitations apply to this PB and the relevant datasets, but there are also promising methodological developments. First, the indicator used does not capture all reactive nitrogen as it does not include biological fixation. It can therefore be argued that the methodology underestimates the transgression of the boundary. Work is ongoing in the Biodiversity Indicators Partnership to assess total per capita loss of reactive nitrogen as a single indicator, and this data could be used to track national performance on the original nitrogen fixation boundary. Data are being developed for all countries but are not yet publicly available.[14]

Second, the bar charts above only display territorial use and not consumptive use of nitrogen, i.e. how much nitrogen is used worldwide to produce the goods and services consumed within national borders. Analysis of embedded nitrogen in goods and services is emerging, but consumptive data are currently only readily available for the United States and the Netherlands (Haq, Bailey et al. 2001). More countries are being assessed and the results will be presented for a range of countries, including Sweden, in the coming years.[15] It should be emphasised that the difference between territorial and consumptive performance is probably larger for nitrogen than for climate change. A number of highly developed countries (e.g., Japan, Switzerland) have very limited per capita territorial use of nitrogen, but a consumption based indicator is likely to show much higher per capita use as these countries import a large proportion of their agricultural and food products.

Finally, the original nitrogen PB definition has been criticised for having been set arbitrarily (Schlesinger 2009) and for being based on the human driver (nitrogen fixation) rather than the resulting state of or impact on the environment. However, the per capita boundary of 5 kg per year corresponds well with the amount of nitrogen in urine and faeces that could be reused, closing the nutrient loop. For example, Swedish citizens excrete on average 12.5 g nitrogen per day, equivalent to 4.6 kg per year (Jönsson et al. 2005) and limiting nitrogen use to this level is arguably in the right order of magnitude.

It is also the case that before planetary thresholds are transgressed and global oceanic anoxia occurs, local freshwater eutrophication boundaries will have already been transgressed (Carpenter and Bennett, 2011), and nitrogen emissions have other negative effects on landscapes and biodiversity in addition to eutrophication. Specific, bottom-up local boundaries based on the local impact of reactive nutrients as well as eutrophication and hypoxia are therefore perhaps more relevant as an absolute national boundary. One suggestion for a comparable national indicator would be to measure average water pollution levels (WPL) in terms of dissolved inorganic nitrogen (DIN) and measure

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[14] Personal communication with Albert Bleker, November 2012. For more information see http://www.bipindicators.net/nitrogenloss

[15] Personal communication with Allison Leach, November 2012. For more information, see N-print project webpage http://www.n-print.org/

this in all countries. Such data are not readily available but global assessments of WPL have recently been made available by Liu et al. (2012).

To summarise, a relevant per capita nitrogen boundary of 5 kg / per capita could be established and territorial performance can be measured and compared. Although there are some uncertainties over methods and indicators, future scientific progress should make it possible to compare consumptive use of nitrogen and therefore also national consumptive performance.

4.1.3 Freshwater use

The original PB for *freshwater use* (Pressure) was developed based on the finding that a critical threshold is often crossed if withdrawals of renewable water resources in a watershed exceed 40% (Rockström et al. 2009). As a cumulative effect of such local/regional water scarcity thresholds, the global hydrological cycle may then be at risk. There are two approaches to the top-down downscaling of this PB. The bluntest way is to calculate the "safe amount" of freshwater that humans can consume globally (i.e., 40% of total global renewable water resources, which corresponds to 4000 km^3) and divide this by the world population. This yields a boundary of 585 m^3 per capita/year (Table 4). Such a boundary would completely disregard local availability and scarcity problems, as well as differences in need. Another, slightly less blunt, option is to define country-dependent boundaries, by limiting withdrawal to 40% of nationally available freshwater, given that unprocessed freshwater resources are not traded on a significant scale (Table 4). However, this approach also has limitations as it does not take account of the fact that freshwater reserves are often shared across national borders, and that the critical thresholds of what is a sustainable consumptive water withdrawal may vary around the 40% rule-of-thumb.

Table 4. Options for downscaling the freshwater use boundary

Planetary Boundary	**Per capita (current population)**		**Absolute**	
Freshwater use	Territorial performance	Consumptive performance	Per capita * national population	Country-dependent (relative to national resource base)
Unit and data set	**m^3 / capita / y** *Pacific Institute (2012)*	**m^3 /capita / y** *Mekonnen & Hoekstra (2011)* (virtual blue water footprint)	**km^3 / y** (territorial or consumptive)	**km^3 / y** *Pacific Institute (2012)*
National boundary	**585 m^3 / capita / y** Rockström et al. (2009) divided by world population		**Eg., Sweden: 5.5 km^3 / y**	**40% water withdrawal, eg., Sweden: 73 km^3 / y**

Unlike the climate change and nitrogen PBs, the freshwater PB has not yet been transgressed at a global level. Figure 13 shows which countries transgress their country-dependent boundaries (Israel and Switzerland) and which countries are approaching their boundaries (India, Belgium, Korea, Macedonia and Spain). Clearly, the level of development is not central to explaining differences in national performance, as it is with CO_2 emissions or nitrogen use. Instead, geography and population density are important factors. As is emphasised above, this is a crude measure of national water scarcity and these results do not indicate which watersheds, or which countries, are particularly critical to the global hydrological cycle or the climate system.

We have chosen not to report territorial performance by country on the per capita boundary (585 m^3 per capita per year). Given that freshwater extraction is so intimately connected to locally available resources, it makes little sense to compare countries in relation to the global resource base. Reducing Sweden's direct freshwater use would do nothing or very little to improve water scarcity in India, for example. However, measuring consumptive performance on the per capita boundary is highly relevant, since it says something about how well water is used globally and the responsibilities countries have for indirectly causing water scarcity elsewhere. We thus compare the per capita boundary with the freshwater embedded in goods and services (Ashok and Arjen 2008; Arjen and Mesfin 2012). There are estimates available for the consumptive water use of most countries in the world through the work on "virtual water" and water footprints (Mekonnen and Hoekstra 2011). However, the methods used in Rockström et al. (Rockström, Steffen et al. 2009; Rockström, Steffen et al. 2009; Rockström et al. 2009) differ slightly from those applied in virtual water analysis and have different estimates of global blue water use. Our approach is therefore to rescale the data on individual countries' consumptive blue water use found in Mekonnen and Hoekstra (2011) to match the original boundary. In other words, we allocate the current global freshwater use estimate of 2600 km^3 used in the original publication to each country with the help of the water footprint data on each country in Mekonnen and Hoekstra (2011) Figure 14 shows national consumptive performance.

Interestingly, a consumptive measure means that more countries in the dataset transgress the boundary. This can be explained by the fact that many of the countries included here are highly developed countries (e.g., including all of the OECD countries), which tend to consume water-intensive goods and services. In a few cases (Israel, Spain and India) there appears to be a correlation between relative local water scarcity and high consumptive performance, possibly explained by the need to import water-intensive products that cannot be produced domestically due to water scarcity. However, there are more examples of the opposite, where countries with high national water scarcity only modestly consume water-intensive products (e.g. Switzerland) or countries with low national scarcity which have high levels of consumption (e.g., US, Australia).

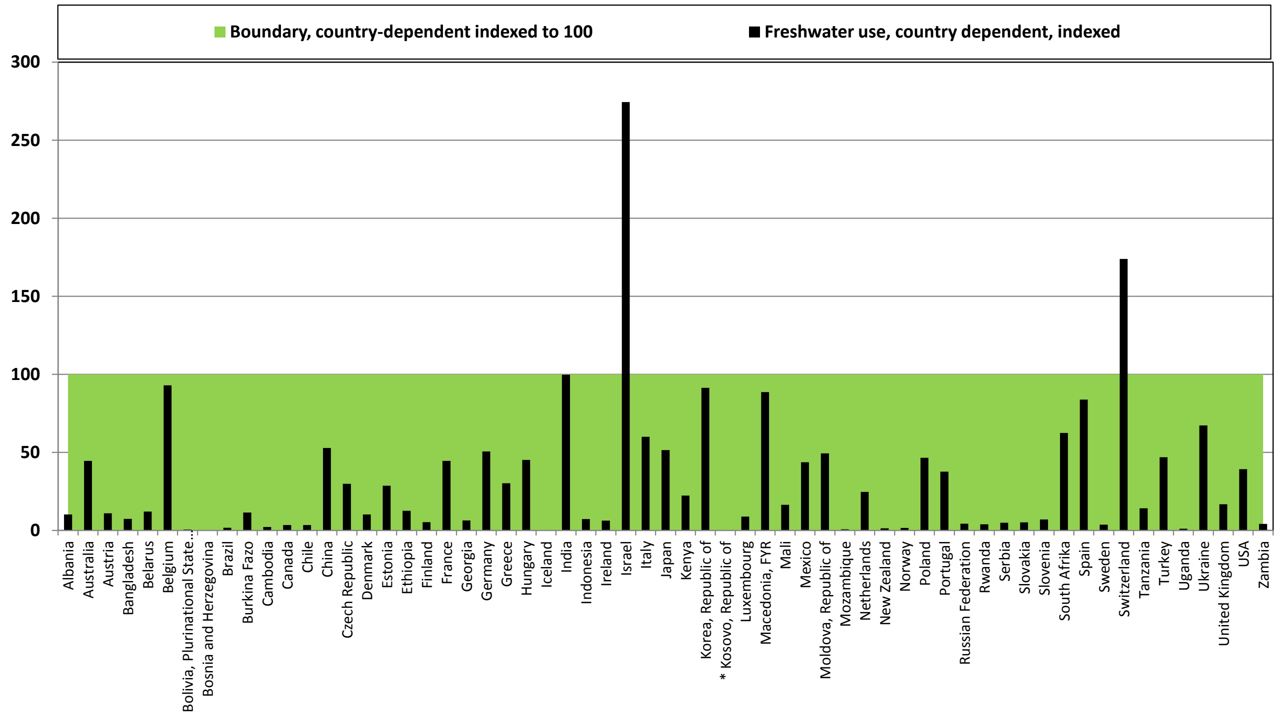

Figure 13. Freshwater use, performance on country-dependent boundaries, most recent available data from the Pacific Institute
Data source: Pacific Institute (2012), data for latest year available (1994–2010) used for each country. *No data for Kosovo.

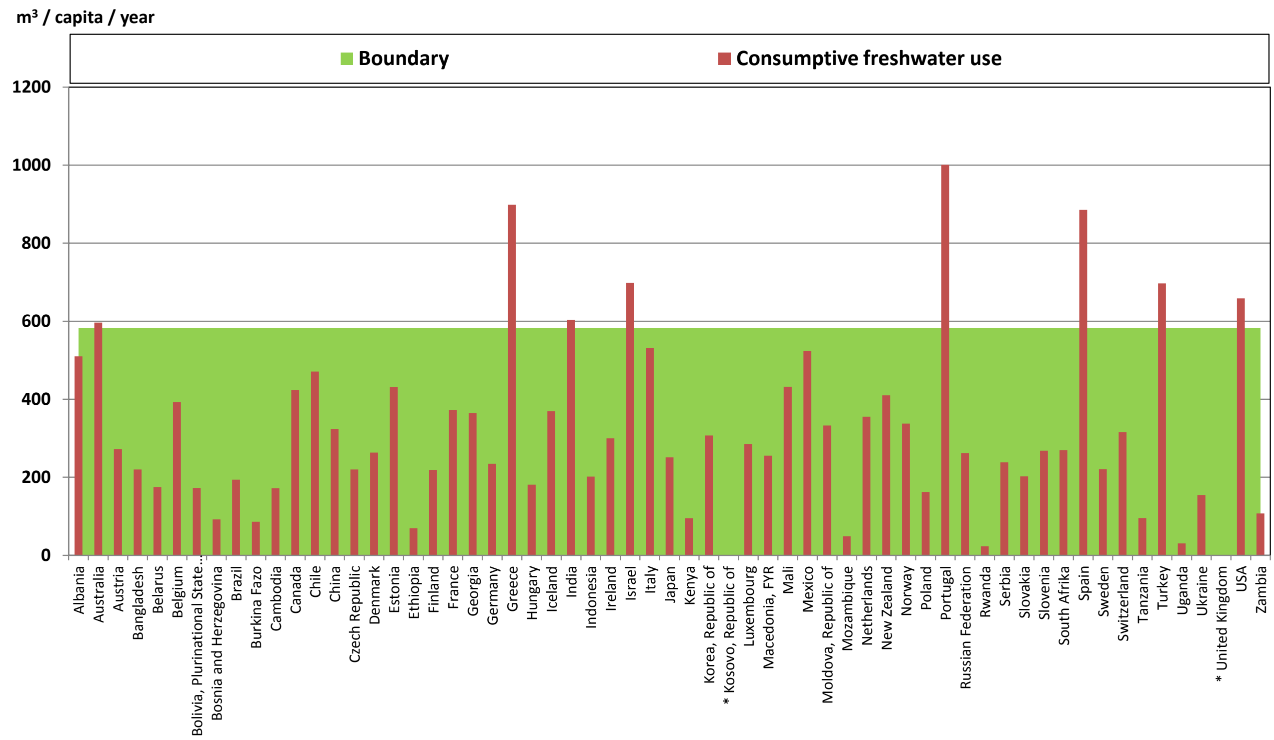

Figure 14. Freshwater use: performance on consumptive per capita boundary, 1996–2005
Data source: Based on Mekonnen and Hoekstra (2011) but rescaled to match consumptive water use in Rockström et al. (Rockström, Steffen et al. 2009; Rockström, Steffen et al. 2009). No data for Kosovo or the United Kingdom.

To sum up, the main limitation with these downscaled boundaries and performance indicators is the importance of locally (more so than nationally) available freshwater resources, which makes a uniform per capita boundary a very blunt instrument. Furthermore, the 40% rule of thumb does not capture variations in the location of water extraction thresholds. Finally, the PB in itself does not provide any guidance on which watersheds around the globe may be more influential in the global hydrological cycle. Nonetheless, the consumptive performance indicator does manage to highlight global interconnectivity in the use of water, and we conclude that it is a reasonable first step to measure national performance on the planetary boundary of freshwater use. In addition, the performance indicator on country-dependent freshwater use could also be combined with other indices of local and national water scarcity.

4.1.4 Land use change

Originally, the PB for *land use change* was defined as a maximum of 15% of the ice-free land being used for cropland (state), with an additional consideration that the conversion of forested areas to cropland must be limited to avoid the risk of losing globally critical carbon storage capacity, of changing the albedo effect and of habitat destruction. This definition is now being reconsidered to make it more place-sensitive and biome-focused, i.e., more sensitive to the kind of forested area that is maintained. Downscaling this PB follows the same two lines of argument used for the freshwater boundary. The bluntest way is to calculate the safe amount of ice-free land that humans can convert globally, i.e., 1995 Mha (Rockström, Steffen et al. 2009), and divide that by the world population. This yields a boundary of 0.3 ha (Table 5). Like freshwater, this completely disregards local land availability. The simplest, but still crude, option for making the downscaled boundary dependant on local land availability is to limit national conversion of land to cropland to 15% of nationally available land. Using Sweden as an example, such a country dependent boundary would derive 2.7 Mha. We present such data in this report. It is beyond the scope of this report to assess the ice-free land for each country. We therefore use 15% of the national land area as the boundary.

Table 5. Options for downscaling the land use boundary

Planetary Boundary	**Per capita (current population)**		**Absolute**	
Land use	Territorial performance	Consumptive performance	Per capita * national population	Country-dependent (relative to national resource base)
Unit and data set	**ha / capita** *FAO (2012)*	**ha / capita** *SERI (2012)*	**Mha** (territorial or consumptive)	**Mha** *FAO (2012)*
National boundary	**0.3 ha / capita** Rockström et al. (2009) divided by world population		**Eg., Sweden: 2.7 Mha**	**15% land use, eg., Sweden: 6 Mha**

Figure 15 suggests that a high number of countries, including both developed and developing countries, transgress their country-dependent boundaries. Those countries which are within their boundaries tend to be less densely populated. The usefulness of these results is limited, primarily because we use FAO data on total land, which is readily available, and this introduces some errors as the original boundary specified ice-free land. The country-dependent boundaries and data in Figure 15 show the countries which use the most of their land for crop production. However, as conditions for agricultural production vary greatly and food and agricultural commodities are internationally traded to such a large extent, a better comparison would be consumptive use of global land.

Land use change driven by consumption has been discussed in the Swedish context (e.g., Naturvårdsverket 2010c) and global estimates of consumptive land use (i.e., land use as embedded in goods and services) have been developed for most countries by SERI using FAO data (Bruckner 2012). Using the latest data on consumptive cropland provided by SERI we show consumptive performance on the per capita land boundary in Figure 16. Many countries transgress this boundary, and all the OECD countries are either close to or above it. The reason why the global boundary has not yet been surpassed can be explained by the fact that consumption in the most populous countries, such as China and India, is not yet land-intensive. Given the correlations with performance on the country-dependent boundaries, it is clear that some small countries with high levels of national land scarcity also import relatively land-intensive goods and services (e.g., Belgium and Denmark). However, countries with no domestic land scarcity (e.g., Sweden, Australia and Russia) also appear to rely on importing land-intensive goods and services. This could be because large areas of land are unsuitable for agriculture (e.g., arid areas or tundra) but it could also be linked to consumption patterns (e.g., high levels of meat consumption).

The key limitation with the original boundary, and therefore any downscaled boundaries such as those discussed above, is that the control variable was chosen as cropland only, whereas negative impacts also follow from other land use change processes such as to built areas, intensively managed forests and pastures. It is also the case that the environmental impacts of land use vary with management practices, as well as the properties of the biome in which the land area is located. The land use change boundary has therefore been criticised for being based on an arbitrary expansion factor from the current level of 12% cropland (Bass 2009), and for being indifferent to the quality aspects of land. However, the rationale for including land use change in the PB framework was primarily the effects on the energy balance and atmospheric circulation due to changes in the albedo effect (Rockström, Steffen et al. 2009; Rockström, Steffen et al. 2009) and the 15% boundary was set in relation to the risk of altering such global processes – not primarily for the impacts on biodiversity or carbon storage. Work is ongoing to revise the planetary boundary on land use based on the above critiques. An updated boundary definition will possibly enable a better downscaled boundary.

To conclude, although the current boundary can be critiqued and might be changed, it can be downscaled to a consumptive boundary on agricultural land use and there is available data to compare consumptive performance.

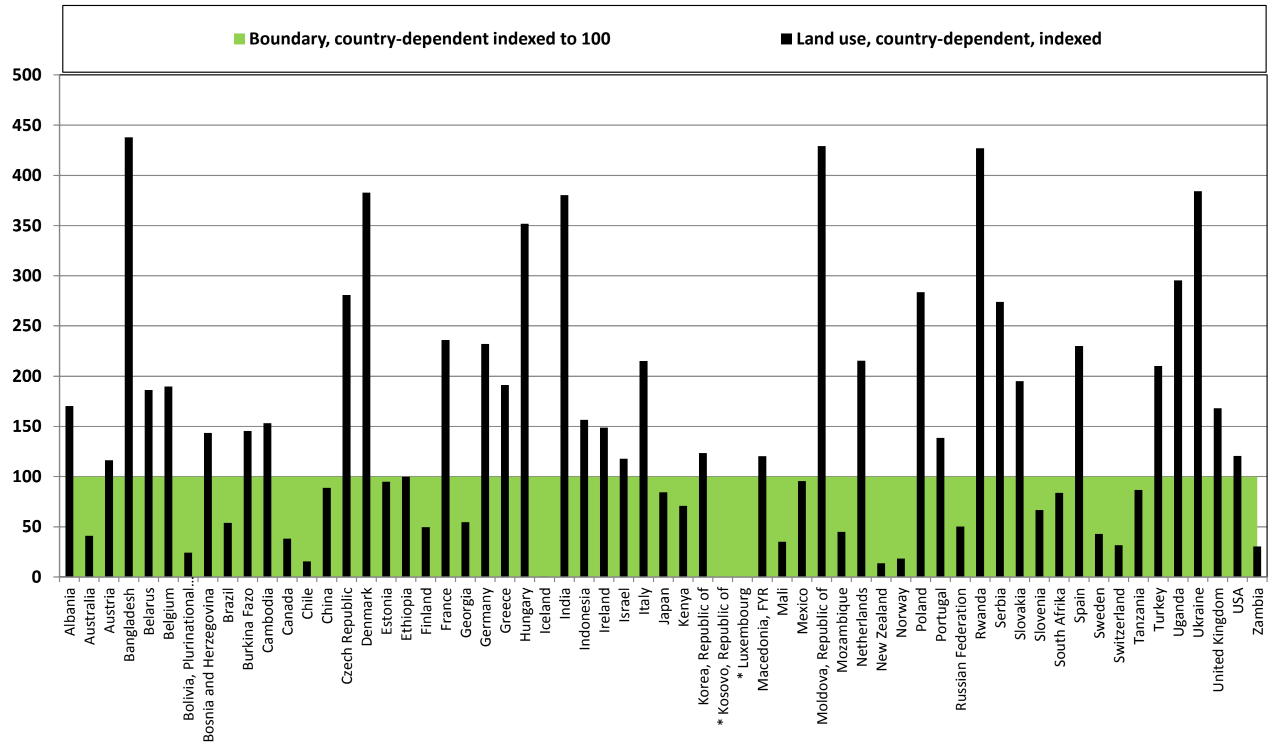

Figure 15. Land use change: performance on country-dependent boundaries, most recent data from FAO
Data source: FAO (2012), most recent available year in 2005–2009. *No data for Kosovo and Luxembourg

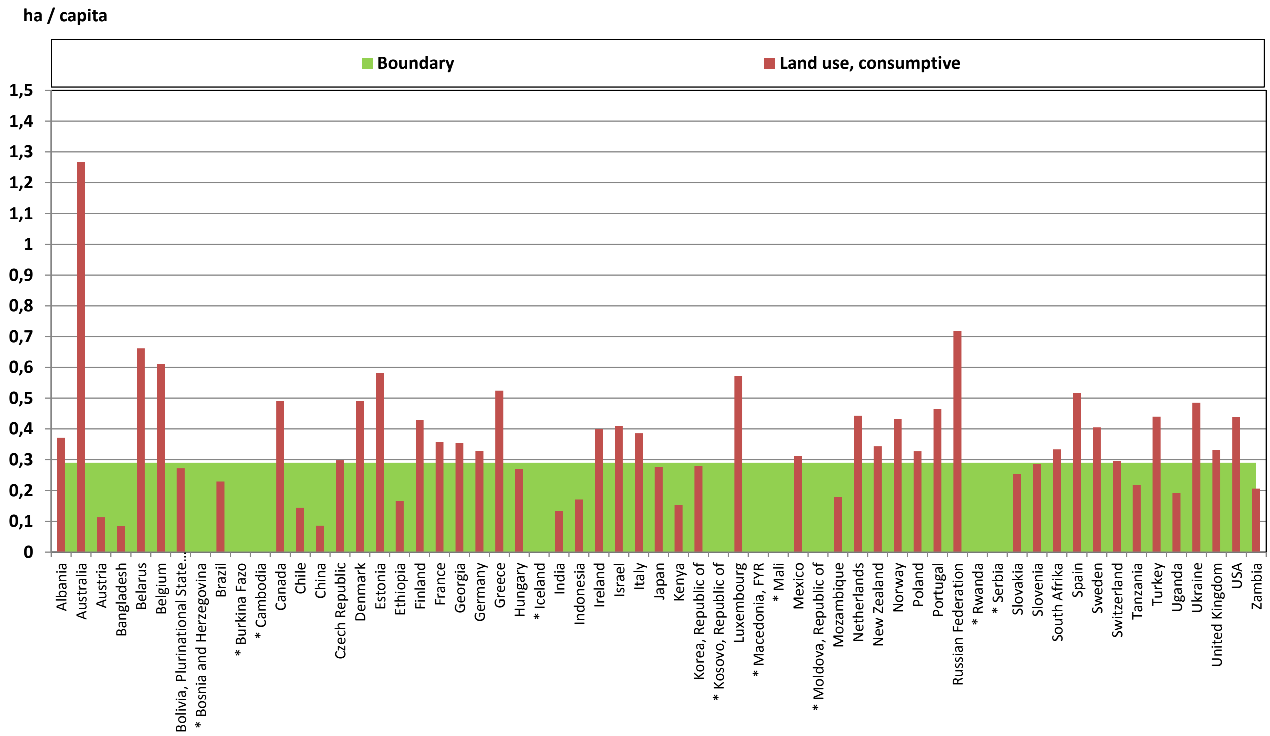

Figure 16. Land use change performance on consumptive per capita boundary: range of data including most recent FAO data
Data source: Modelling by SERI (Bruckner 2012). *No data for Bosnia and Herzegovina, Burkina Fazo, Cambodia, Iceland, Kosovo, Macedonia, Mali, Moldova, Rwanda and Serbia.

4.2 Additional indicators for measuring planetary boundaries

For three of the globaly quantified PBs, a number of limiting factors mean that it is not currently possible to downscale the planetary-level boundaries to the national level in a meaningful way and stay true to the orgininal methods and boundary definitions. For both the *Phoshurous cycle* and *Biodiversity loss* the control variables originally proposed to measure global performance cannot be easily disaggregated. Nor are there reported data at the national level in existing datasets. In both cases there is need for more science. The case of biodiversity loss is particulary difficult as the trends are very long term and the range of uncertainty at the global level is measured in orders of magnitude (e.g., the current rate of extinciton is estimated to be between 100 and 1000 times higher than pre-Anthropocene). For ozone depletion there is the same difficulty as with change change in that a boundary needs to be develoepd for pressure instead of states. Because of the longevity of ozone depleting substances, however, it is unclear how such a boundary on a pressure should be formulated.

There are alternative and policy relevant indicators that address relate to the original PB control variables. For example, in many cases there are good data availiable on relevant drivers behind the changes in state on the original boundaries. Such alternative indicators are proposed below, with commentary on the limitations on data and methodology. It is important to remember that these alternative indicators represent different variables that may not be associated with threshold behaviour in the same way as the original PB.

4.2.1 Stratospheric ozone depletion

The original *stratospheric ozone depletion* PB is defined as the global average thickness of the ozone layer (state). This boundary was previously transgressed at the global scale (Rockström, Steffen et al. 2009), but the trend since the 1990s is positive with a gradual buildup of average ozone layer thickness (WMO 2010). Although the depletion of the ozone layer has proved to be reversible without a major hysteresis effect, a low level of ozone continues to cause local effects. There is also a strong linkage between this boundary and the *climate change* boundary since several substances introduced as substitutes Ozone Depleting Substance (ODS) are potent greenhouse gases. Moreover, global warming has been linked to increased ozone depletion in the stratosphere.

Due to the longevity of ODS and the fact that much of the use of ODS has alrady been phased out, essentially removing the driver behind ozone depletion, the global PB of a 5% reduction in the thicknes of the global ozone layer (state) cannot easily be translated into national variables on emissions (pressure). However, a relevant indicator for measuring national territorial performance is the use of ODS as measured in Ozone Depleting Potential (ODP) in tonnes.[16] Data on this indicator are presented as national absolute and per capita performance (Figure 17).

[16] Note that use of ODS is usually referred to as consumption of ODS. However, we use "consumptive" and "consumption" to refer to indicators in which trade has been accounted for.

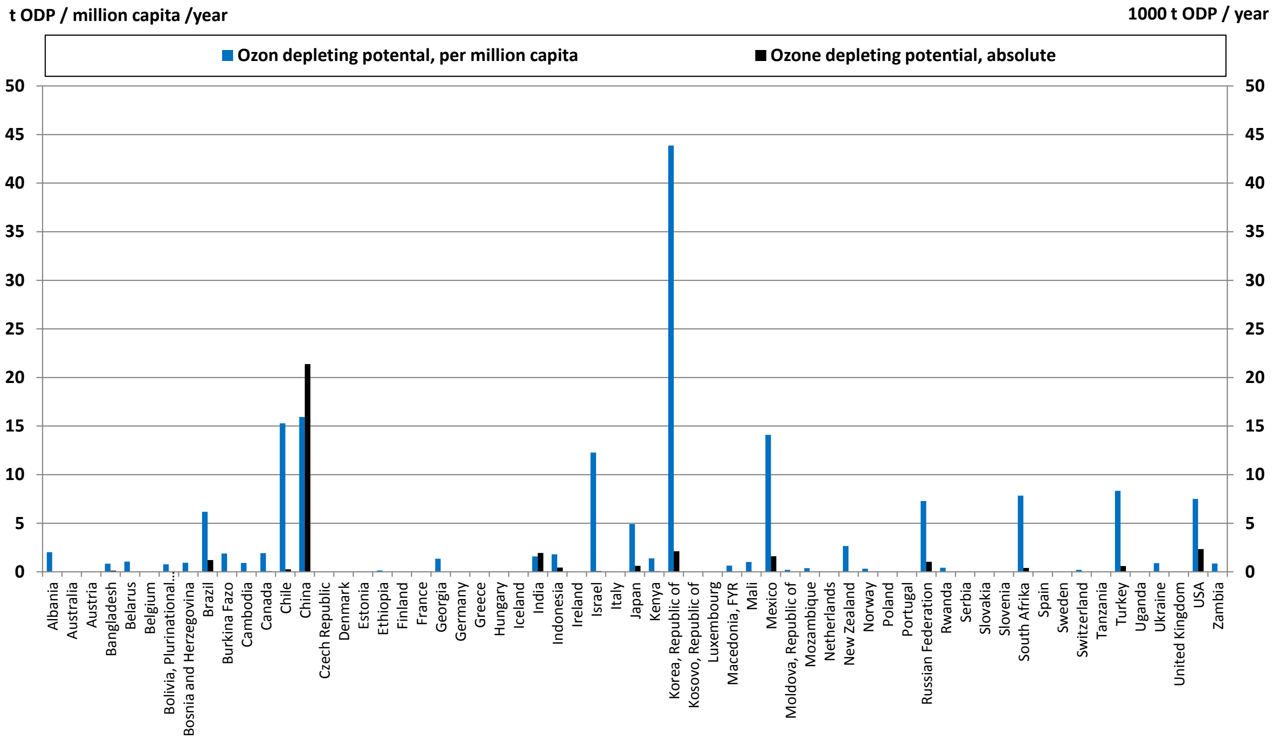

Figure 17. Ozone depletion potential from the use of ozone depleting substances, territorial and absolute, 2010
Data source: UN (2012) for 2010. MDG indicator 7.3, data reported to UN under the Montreal Protocol.

Note that the use of ODS in 2010 among EU member states was zero.[17] This graph illustrates the success with which the use of ODS has been reduced in many countries, following the Montreal Protocol. Countries with relatively high use tend to be emerging or middle income countries, with Russia and the US as exceptions. Nonetheless, the graph does not convey the harmful climate effects of the ODS remaining in the stratosphere.

4.2.2 Biodiversity loss

The intention of Rockström et al. (2009) was to define a quantifiable safe boundary level for the *rate of biodiversity loss* that, if transgressed for long periods of time, could result in undesirable changes in the Earth system at the regional to global scales. However, even if there are signs that we may be approaching a state shift in the Earth's biosphere (Barnosky et al. 2012), science is, as yet, unable to provide a boundary measure that captures, at an aggregate level, the regulating role of biodiversity. Instead, the extinction rate was suggested as an interim indicator or substitute. The primary reason for including biological diversity as a PB is its role in providing ecological functions that support the biophysical subsystems of the Earth, and thus provide

[17] For latest assessment of production and consumption of ODS in Europe see http://www.eea.europa.eu/data-and-maps/indicators/production-and-consumption-of-ozone/production-and-consumption-of-ozone-3

the underlying resilience of other PBs. Biodiversity has been described as one of the four "slow" boundaries (Rockström and Klum 2012), which seem to be associated with local-to-regional scale thresholds rather than global ones. There is mounting evidence that an accelerating rate of biodiversity loss has the potential to disrupt ecosystem functioning and services and allow ecosystems to shift into undesired states (e.g., Cardinale et al. 2012). There are a number of examples from local to regional scale ecosystems (e.g., lakes, forests and coral reefs) of such abrupt changes when critical thresholds of biodiversity and other key variables are crossed (e.g., Scheffer, Carpenter et al. 2001).

Scaling down the biodiversity boundary to a national level does not necessarily make the task easier – the same methodological challenges also exist at this scale. Therefore, we suggest three possible alternative indicators to measure the relative performance of countries:

(1) the number of species threatened within the national territory per million capita (territorial performance), using data from Lenzen et al. (2012);
(2) the number of species threatened globally, driven by consumption including international trade (consumptive performance), using data from Lenzen et al. (2012); and
(3) the percentage of marine and terrestrial areas protected, using data from the world database on protected areas (IUCN and UNEP-WCMC 2011).[18]

The first two are important as they estimate the performance of countries in a similar manner to other per capita indicators, e.g., on climate change, and therefore say something about the role of different lifestyles. The second indicator also shows the impact of consumption in one country on biodiversity loss in other countries. A data visualisation tool created for this second indicator even shows which particular species are threatened in which particular countries as a result of the importing country's consumption.[19] The third indicator is relevant from a political point of view as it corresponds directly to important aspects of the Aichi Biodiversity Targets (see Annex III). Target 11 states that by 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas should be protected areas and integrated into the wider landscape and seascape.

National performance on the first and second indicators is shown in Figure 18. The results are difficult to interpret and there is no obvious difference between developing and developed countries. It is clear that countries with smaller populations perform worse on the indicator for domestic species threats per million capita. This suggests that a per capita indicator for domestic species threats is of limited usefulness for understanding where the real

[18] See http://www.wdpa.org/.
[19] See http://www.worldmrio.com/biodivmap/about.htm

biodiversity loss hotspots are. The link between population and consumption, and biodiversity loss is much less straightforward than for example between these two and CO_2 emissions. In order to show which countries face the most species threats in absolute terms, and are therefore the most important partners in international cooperation, such data is presented in Figure 18. There appears to be some correlation with country size (area) but clearly other factors are also important.

Lenzen et al. (2012) discuss species threats driven by consumption and exerted through international supply chains, and conclude that in many developed countries the consumption of goods such as coffee, tea, sugar and textiles cause larger threats to biodiversity abroad than their domestic species threats (represented in Figure 18 by the red bars exceeding the blue bars). In other words, rich countries are net importers of species threats, exported from developing countries where the actual species threats occur. Reducing "biodiversity footprints" would therefore entail addressing both consumption patterns in the importing country and production methods in the exporting country.

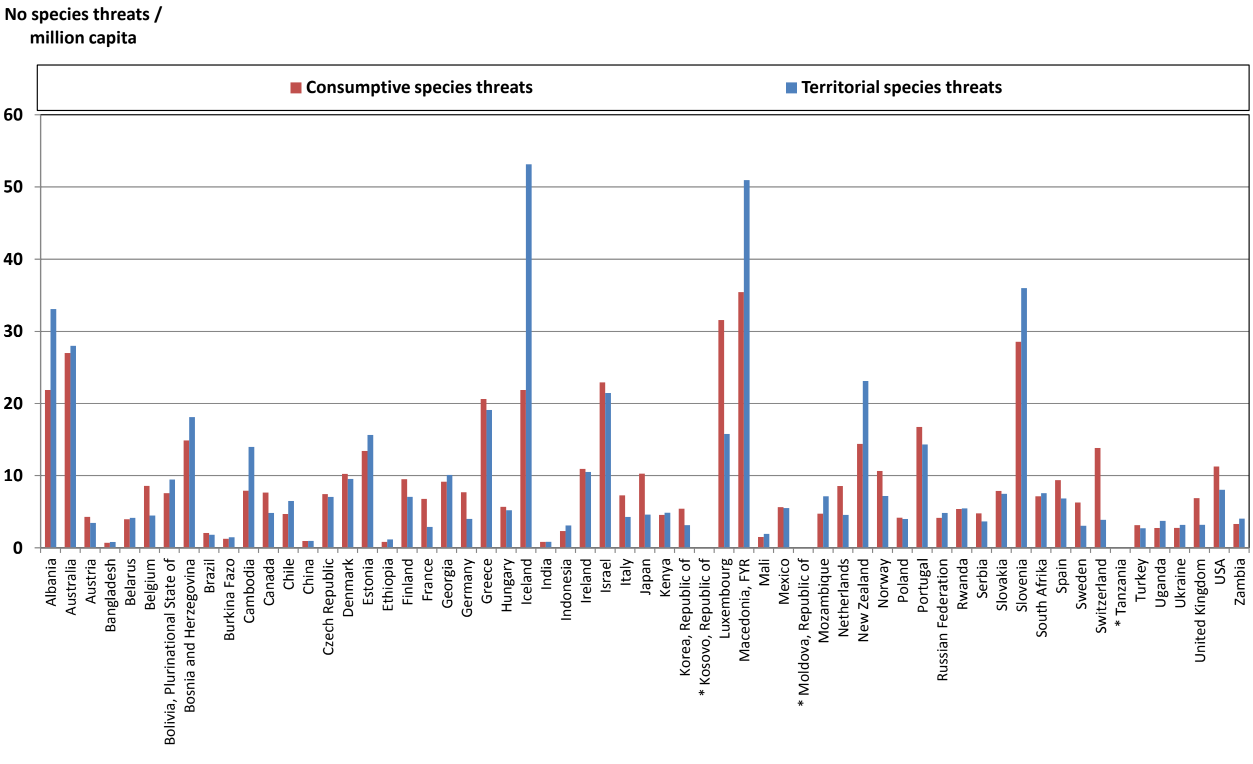

Figure 18. Biodiversity loss: performance on species threats per million capita, territorial and consumptive, 2012
Data source: Lenzen et al. (2012) based on IUCN species listed as "threatened", shown as per million capita. *No data for Kosovo, Moldova and Tanzania.

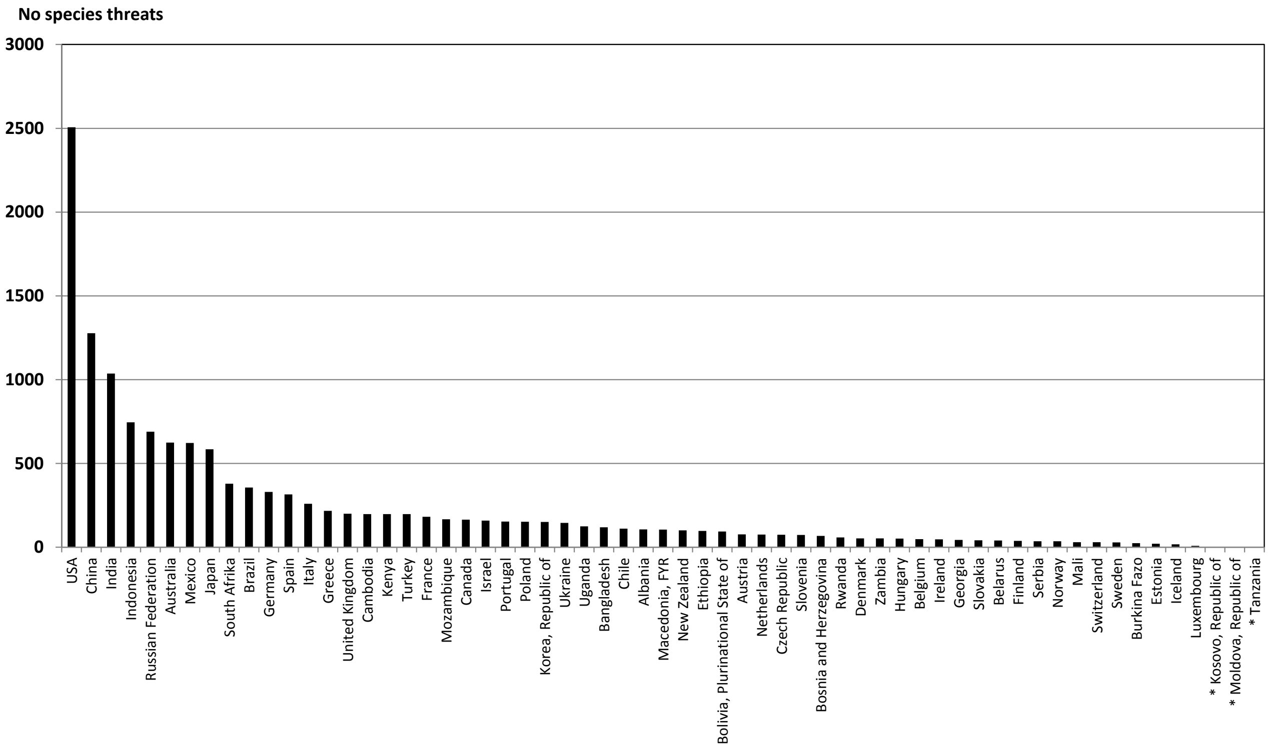

Figure 19. Species threats, domestic, 2012
Data source: Lenzen et al. (2012). No data for Kosovo, Moldova and Tanzania.

Turning to the third indicator, Figure 20 shows the size of terrestrial and marine protected areas combined as a percentage of total territorial marine and land area. There is a significant variation between countries but no clear pattern or explanation why some countries have a higher percentage than others. This report compares a set of countries of which many are landlocked without marine areas. For this reason, the most relevant comparison in relation to the Aichi Targets is the percentage of protected terrestrial area, with the goal of 17% as a benchmark (shown in Figure 20). Note that the Aichi Target is somewhat crude, in that the area that could de facto be protected in a country depends on urban area, population density and other factors. Furthermore, the exact legal status of protected areas may also differ among countries. Recognising this limitation, the results suggest that almost one-third of the countries included here achieve the target. There is no clear pattern in terms of countries performing well or badly on this target: neither developing country status nor country size appears to be a factor.

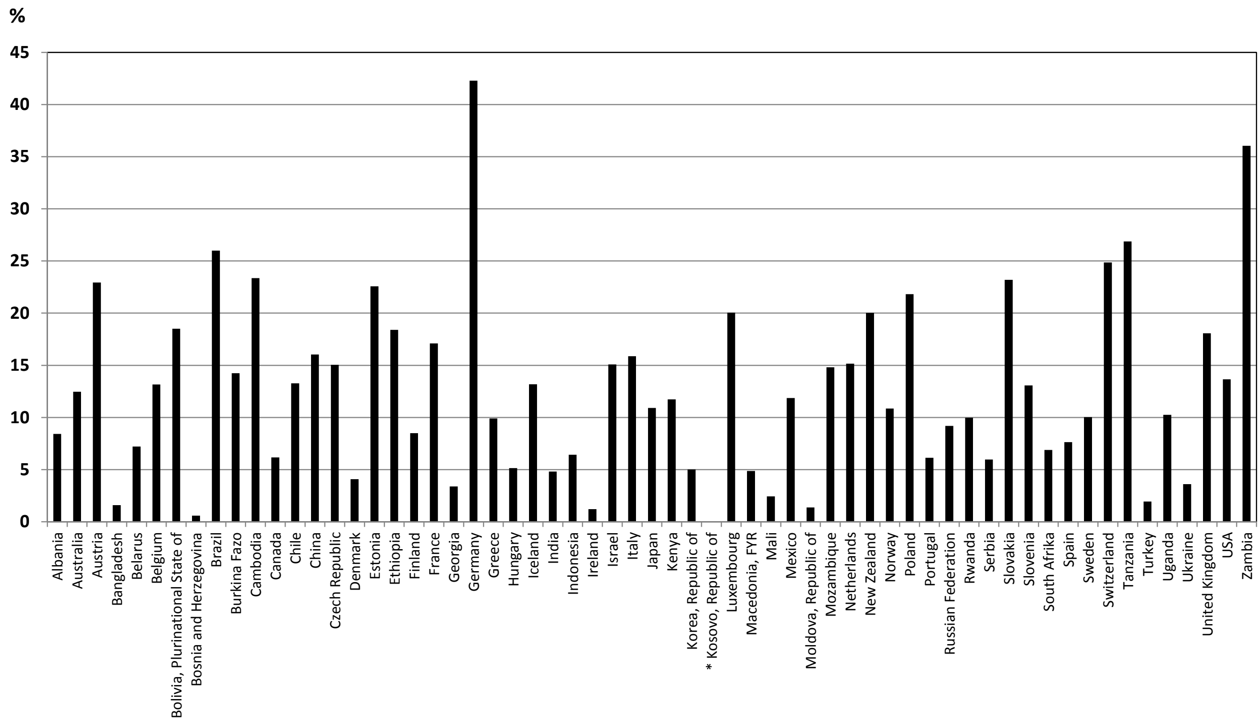

Figure 20. Protected marine and land area as percentage of national territory, 2010
Data source: World database on protected areas (IUCN and UNEP-WCMC 2011). *No data for Kosovo.

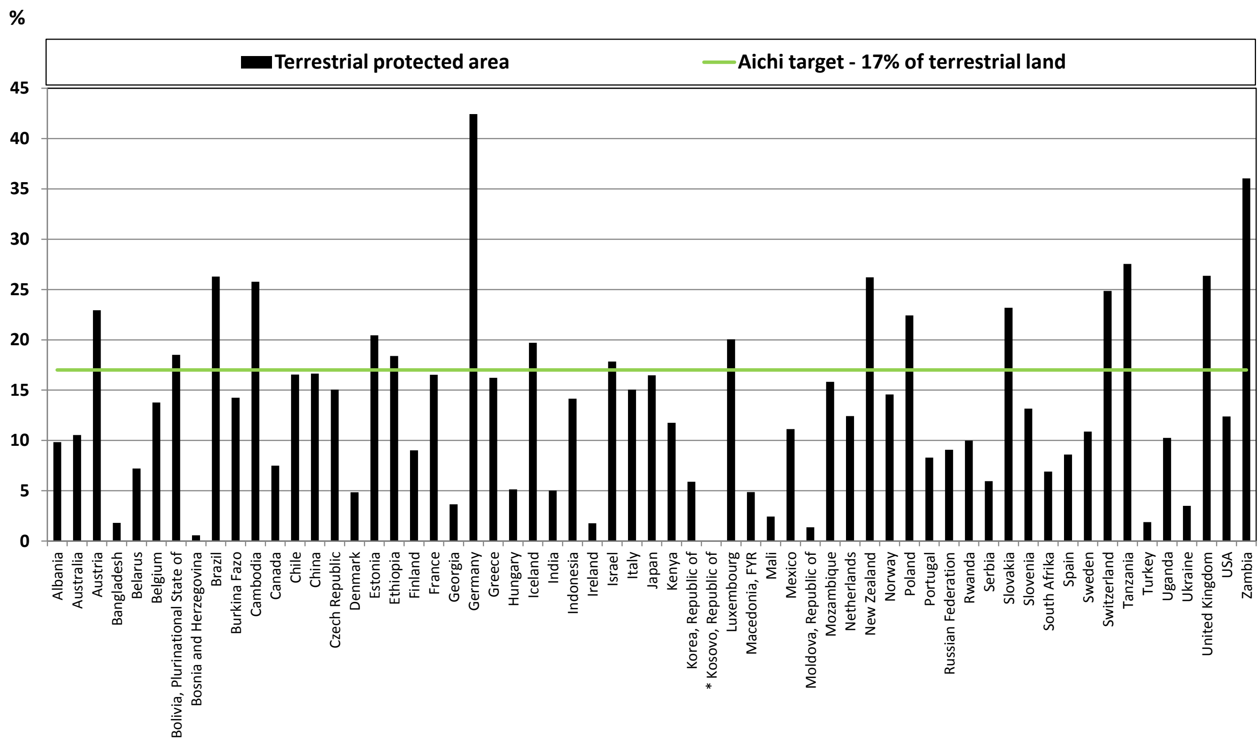

Figure 21. Terrestrial protected areas in 2010 and Aichi biodiversity target 11
Data source: World database on protected areas. *No data for Kosovo.

Although the PB for biodiversity cannot be meaningfully downscaled, we have identified three alternative indicators for measuring national performance on important aspects relating to biodiversity loss. However, some important caveats apply to these results. First, it is important to emphasise that these indicators on species threats and protected areas are far from completely addressing the problems alluded to by the PB. The data from Lenzen et al. (2012) shown in figures 18 and 19, are based on the IUCN's red lists, which exclude biodiversity threats to species not yet evaluated or where data are lacking (see the supplementary information to Lenzen et al., 2012)[20]. For the third indicator, it is also important to keep in mind that areas outside of protected areas, e.g., areas under agriculture, aquaculture and forestry, must be managed sustainably to ensure the conservation of biodiversity and ecosystem services (Aichi target 7). Moreover, none of the indicators chosen addresses the need to maintain genetic diversity in cultivated plants, and farmed and domesticated animals and their wild relatives, including other socio-economically as well as culturally valuable species (Aichi target 13).

A more detailed discussion of the difficulties associated with setting targets and finding suitable indicators for biodiversity from a functional perspective, in terms of maintaining resilience and avoiding tipping points that threaten the long-term provisioning of ecosystem services, can be found in Huitric et al. (2009).

4.2.3 The phosphorus cycle

The original PB on the *phosphorus cycle* was included to reflect the risk of a global ocean anoxic event that would trigger a mass extinction of marine life (Handoh and Lenton 2003). It was defined as a maximum annual inflow of reactive phosphorus to the oceans (pressure) and set at 11 Mt per year. The original definition was criticised, partly because of the uncertainty of the science (Schlesinger 2009). There are no easily accessible data on global estimates of reactive phosphorus emitted by countries and the original boundary was based on data from modelling by Mackenzie et al. (2002). In addition, recently published indicators based on the reactive phosphorus and nitrogen transported by water are based on modelling and only provide data at the watershed level (Liu, Kroeze et al. 2012). We found no reliable data that allow for a simple downscaling to the national level. Another criticism of the original definition was the lack of attention to local and regional scale eutrophication thresholds. Carpenter and Bennett (2011) have therefore proposed a set of redefined boundaries that are applicable at the local and the national level. However, these redefined boundaries are not considered here.

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[20] Lenzen et al. (2012) only include species assessed as threatened (i.e., "critically endangered", "endangered", and "vulnerable", excluding the extinct categories, near threatened and of least concern. For more information see IUCN (2011) Guidelines for using the IUCN red list categories and criteria are available at http://www.iucnredlist.org/documents/RedListGuidelines.pdf

One approach that could be explored would be to change the control variable from reactive phosphorus emitted in to the oceans (pressure) to phosphorous use, measured as the phosphorus content of national fertiliser use. Such an indicator would be defined as a driver, in the same way as the current nitrogen cycle boundary is defined as such. However, there is a lack of scientific data on the causal link between the use of phosphorous and ocean inflow. Thus, we cannot claim that we have downscaled or directly measured the PB as originally defined at the national level. Figure 22 provides data on the phosphorus content of fertiliser used by countries.

This indicator provides a comparison of national performance on the relevant driver behind the development of the PB and highlights that there are very large differences in the performance of countries. The use of Phosphorous depends on a range of factors, such as the type of agricultural system. There are also large uncertainties in the data reported to FAO. Furthermore, the analysis of Carpenter and Bennet (2011) means that work is now ongoing to revise this boundary, and this work might have implications on the selection of an appropriate driver to compare national performance. Finally, the data presented are on territorial use (e.g., they take a production perspective) and no studies of consumptive phosphorous use have so far been identified.

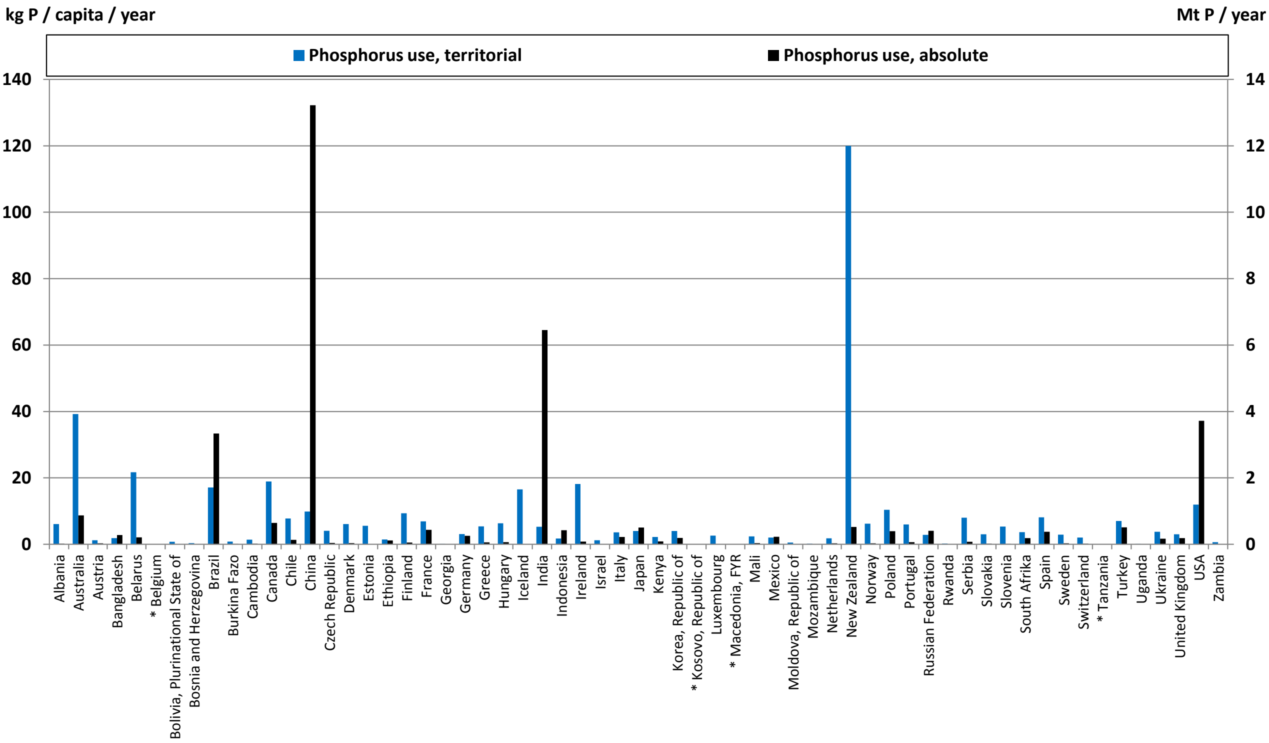

Figure 22. Territorial and absolute performance on the use of phosphorous in fertilisers, 2006–2010
Data source: FAO (2012), average of 2006–2010 *No data for Belgium, Kosovo, Macedoina and Tanzania.

4.3 Comment on remaining planetary boundaries

For the remaining planetary boundaries we have not been able to either develop a downscaled boundary or provide indicators that can track the globally quantified planetary boundary. This is partly due to our approach of keeping strictly to the original PB definitions. However, on climate pollution we provide a longer discussion and some suggestions for relevant indicators that could be developed.

4.3.1 Chemical pollution

As the PB on *chemical pollution* has not yet been defined or quantified, there is no planetary level boundary to downscale to the national level. Work is ongoing to select an appropriate indicator and quantify a boundary, but the results are not yet available. The chemical industry sector is growing rapidly (UNEP 2012b) and there is an extremely large number of chemicals in production and use (at least 30,000) (Naturvårdsverket 2010a). The number of chemicals in use, the multiple uses of these substances and their multiple effects on humans and the environment make bringing chemical pollution or chemicals management in the PB framework extremely challenging.

Recognising that proposals for a PB for chemical pollution will probably be made in the near future, we present below some suggestions for indicators and methods. For the purpose of comparing the performance of different countries, a first step will be to use a combination of indicators at different stages in the DPSIR framework. Our suggestion would be to choose among the following set of relevant indicators:

1) Pesticide regulation (response) – the Environmental Performance Index reports an indicator of the extent to which pesticides containing persistent organic pollutants (POPs) have been banned in countries, with data from 2003 (Yale Center for Environmental Law and Policy and CIESIN 2012).
2) POPs in human breast milk (state) – the Stockholm Convention on POPs states that such an indicator should be regularly monitored, but this is not yet reported on an international basis using a standardised methodology.
3) A methylmercury-based indicator (state and/or driver) – Finding a relevant indicator for methylmercury, either in the state or driver category, would be of interest in the light of the new international agreement negotiated for mercury, the 2013 Minamata Convention. This could be a candidate for an indicator but we are not aware of any current broadly based international, standardised measure.
4) Consumptive measures of the embedded use of chemical substances in traded products, e.g., based on substances in the European Pollutant Release and Transfer Register (E-PRTR) (driver) – Sweden has initiated methodological work on applying a consumption perspective to chemicals (Naturvårdsverket 2012b), but we are not aware of any standardised international reporting on such indicators.

5) As part of the international policy framework on the sound management of chemicals, a set of 20 indicators, the Strategic Approach to International Chemicals Management (SAICM 2006), has been developed and is being reported on by countries. The first report was presented in 2012 (UNEP 2012c). These indicators are of a general nature and their interpretation is not always apparent from the first progress report. However, these indicators are now reported on as part of an international process that may complement other efforts. Two examples of these indicators that may be useful are: the number of countries with mechanisms in place for setting risk reduction priorities (response); and the number of countries providing information according to international harmonised standards such as the Globally Harmonised System for the Classification and Labelling of Chemicals (response).

These five suggestions offer snapshots of chemical pollution and chemicals management but do not give the complete picture. To only focus on one chemical, or one group of chemicals, such as POPs, would be a severe limitation. There are newer chemicals that are more problematic but for which there is not enough data to make comparisons between countries. For example, for some countries, levels of POPs in breast milk have decreased since POPs were banned, but concentrations of other substances such as brominated flame retardants in breast milk have increased (Meironyte et al. 1999; Noren and Meironyte 2000). Response type indicators on the adoption of regulation for, e.g., pesticides, and the indicators under the Strategic Approach to International Chemicals Management will only give information about the first step – the introduction of legislation – and say nothing about actual implementation and the enforcement of such legislation. This makes state-type indicators more informative and better candidates for a quantification of the chemical boundary.

Finally, the ongoing work of the Swedish EPA to develop consumption-based indicators for chemicals is an interesting attempt to better capture overall chemicals management and pressure in an indicator (Naturvårdsverket 2012b). When the chemical planetary boundary is quantified, future research could potentially draw on this work to develop consumptive performance indicators for the chemical boundary too.

4.3.2 Atmospheric aerosol loading

As of 2009, the PB for *atmospheric aerosol loading* had not yet been quantified. Although there are many assessments and indicators available for particulate air pollution, such as $PM_{2.5}$ (due to the negative influence on human health), there is not enough scientific knowledge to quantify the impact at the global scale (Rockström, Steffen et al. 2009). Complexity in terms of the variety of particles, sources, impacts, and spatial and temporal distribution make it currently impossible to discuss a critical boundary for the Earth as a whole.

We therefore conclude that, unfortunately, science has not progressed enough since 2009 to propose relevant national indicators that can be used to compare countries' contributions to the global scale effects of atmospheric aerosol loading.

4.3.3 Ocean acidification

This report is interested in policy-relevant national boundaries. As the *climate change* PB is driven by climate change, the relevant downscaled boundary is thus the same as for climate change (see, Figure 8) and we do not include a separate analysis of this boundary.

4.4 Summary

In sum, four of the PBs can be downscaled to a national level, either as absolute or per capita measures. It is also possible to measure territorial and consumptive performance on per capita boundaries for most of them. Table 6 shows how all the downscaled boundaries have been developed and all the relevant data series that are available.

Table 6. Compilation of options for downscaling

Planetary Boundary	Per capita (current population)		Absolute	
	Territorial performance	Consumptive performance	Per capita * national population	Country-dependent (relative to national resource base)
Climate Change	**2 t CO_2 / capita / y** *UNDP (2007)*		**Eg., Sweden: 18 Mt CO_2 / y**	n/a
Nitrogen cycle	**5 kg / capita / y** Rockström et al. (2009) divided by world population		**Eg., Sweden: 45,000 t N / y**	Not yet quantified, but suggestion is WPL<1
Freshwater use	**585 m^3 / capita / y** Rockström et al. (2009) divided by world population		**Eg., Sweden: 5.5 km^3 / y**	**40% water withdrawal, eg., Sweden: 73 km^3 / y**
Land use	**0.3 ha / capita** Rockström et al. (2009) divided by world population		**Eg., Sweden: 2.7 Mha**	**15% land use, eg., Sweden: 6 Mha**

For an additional set of three PBs we suggest relevant indicators to track the relative performance of countries. We expect further development will be possible on these, in particular for the PB on chemical pollution, after the ongoing revision of the PB framework has been completed. For example, if the chemical pollution boundary is specified and quantified at the global level as a set of several measures of chemical pollution (compare with how the biogeochemical flow boundary consist of two separate boundaries on nitrogen and phosphorous), national boundaries could be developed. Table 7 provides an overview of all the planetary boundaries with a summary of the boundaries and an assessment of data availability.

Table 7. Assessment of data availability for downscaled planetary boundaries

Planetary Boundary	Downscaled boundary	Data availability
Climate change	Per capita CO_2 emissions	+++
Ocean acidification	Not assessed as ocean acidification is an impact of climate change	
Stratospheric ozone depletion	No downscaled boundary. Relevant indicator on emissions of ozone depleting substances.	+
Biogeochemical flows: nitrogen cycle and phosphorus cycle	Nitrogen cycle: Per capita territorial use of N Phosphorous cycle: No downscaled boundary but relevant indicator on phosphorous use	++ +
Atmospheric aerosol loading	No downscaled boundary and no relevant indicator	–
Freshwater use	Per capita freshwater Country dependent (relative national resource base)	+++
Land use change	Per capita land use Country dependent (relative national resource base)	+++
Rate of biodiversity loss	No downscaled boundary but relevant indicator on species threats and protected areas	+
Chemical pollution	No downscaled boundary and difficult to assign relevant indicator without a quantified global boundary	–

Note: '-'= not possible to downscale boundary; '+' = relevant indicators exists, but not possible to downscale boundary; '++' = downscaled boundary and relevant territorial indicator; '+++' = downscaled boundary and relevant consumptive indicator.

5 Addressing the policy questions

This chapter revisits the policy questions identified in the chapter 1 in the light of the performance results reported in chapter 4. Section 5.1 analyses Sweden's performance and discusses the relevance of PB indicators for measuring the achievement of the generational goal. Section 5.2 examines the other side of the international dimension, looking at how global performance affects the achievement of Sweden's NEOs. It describes and tests an approach to quantifying the legal competence deficit of Sweden. This analysis provides some guidance for the discussion in section 5.3 of patterns of country performance on the PBs and how these indicators could play a role in prioritising between potential bilateral cooperation partners. Section 5.4 reviews how well existing IEAs match PBs and where improvements can be made, to close either policy gaps or implementation gaps.

5.1 Sweden's environmental impact abroad and the generational goal

This report is a first attempt to develop national boundaries and relevant indicators, and there are significant uncertainties in the data which are beyond our control. However, viewing all the quantified boundaries and indicators together reduces uncertainty, and we provide below some tentative analysis for Sweden based on this combined picture, or "fingerprint", of Sweden's PB performance. Figure 23 shows Sweden's performance on seven PBs. four of which have a downscaled boundary. Russia, China, and India are included for comparison. The red bars indicate consumptive performance, where such measures are available, and the blue bars territorial performance.

The results (see also figures 9–21) suggest that Sweden performs relatively well compared to other highly developed countries. For example, compared to the members of the Arctic Council, our transgression of the four downscaled planetary boundaries is generally lower. However, Sweden performs worse when comparing consumptive performance. Swedish consumption has negative effects, in particular on climate change, land use change and freshwater use. Swedish territorial nitrogen use is also above the per capita boundary, and if a consumptive measure were available it is likely to be even further above the nitrogen per capita boundary. This shows that Sweden needs to address consumption patterns and lifestyles and thus confirms previous findings on this issue (Naturvårdsverket 2012ad).

On biodiversity, measured as species threats per capita (Figure 18) and phosphorus use (Figure 22), Sweden performs better than some developed countries, but worse than some developing countries. However, some developing countries perform badly on these as well. For biodiversity, where there is a consumptive performance measure available, it is clear that we contribute to more species threats abroad through our trade than within our domestic territory (the red bar exceeds the blue bar) (see Figure 18; see also Lenzen et al. 2012). As is noted above, ozone depletion is the PB on which highly developed countries such as Sweden generally perform better than less developed countries. Ozone depletion is the only PB for which Sweden does not contribute to environmental problems beyond Sweden's borders, due to its zero reported use of ODS.

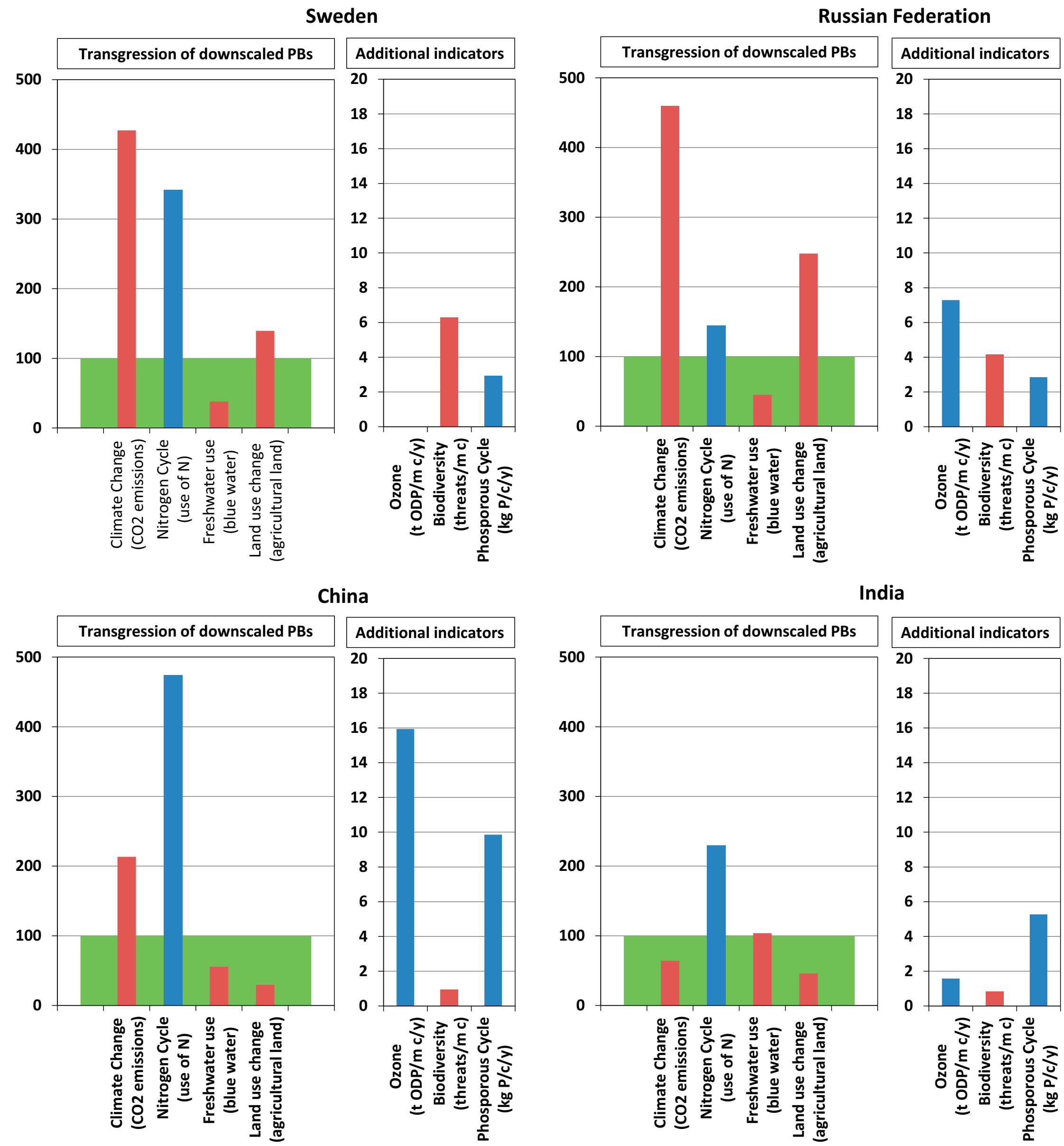

Figure 23. Comparing the national performance of Sweden, the Russian Federation, China and India across downscaled boundaries and relevant indicators

Data sources: See chapter 4. In the left pane of each country graph: Climate Change, Nitrogen Cycle, Freshwater Use and Land Use indicators are indexed to show the boundary at 100. In the right pane of each country graph: Ozone, Biodiversity Threats and Phosphorous Use share the same scale but have no downscaled boundaries.

Three observations can be made on connecting Swedish performance on the PBs to the achievement of the generational goal (to not solve domestic environmental problems by increasing environmental problems beyond its borders). First, Swedish consumption causes environmental problems in other countries. Sweden's performance on the climate change, land use, water use and biodiversity boundaries is significantly worse in consumptive measures compared to territorial measures or country-dependent measures.

Second, the results presented above suggest that the difference between consumptive performance and territorial and country dependent performance (see Figure 24 and Figure 25) is among the highest for Sweden compared to the other developed countries. For example, countries such as the USA have larger domestic economies that are relatively less dependant on imports and exports, and therefore show a smaller difference between territorial and consumptive measures. The conclusion to draw is that we have a relative bigger challenge than other countries with regard to policy goals such as the generational goal. Hence, it is even more important for a small, export dependent country such as Sweden to consider consumptive performance when estimating our global impact and performance on the generational goal.

Third, on absolute performance, the results show that Sweden currently transgresses three of the four quantified boundaries (climate change, nitrogen and land use). Table 8, rightmost column, provides a quantified estimate of by how much Sweden would need to improve its performance to stay within the national boundary for selected PBs. This last observation, in particular, could be interpreted as evidence that **Sweden has *not* achieved its generational goal thus far**. The Swedish EPA has itself published an assessment that the generational goal, including the international dimension, will not be achieved by 2020 (Naturvårdsverket 2012a: 121). The contribution that the PB framework could make to the current set of proposed indicators for measuring progress on the generational goal (see Naturvårdsverket 2012c) is the identification of absolute targets for per capita or country-dependent boundaries.

5.2 Global impact on Sweden: quantifying the Swedish legal competence deficit

The Swedish EPA has already identified those NEOs which it will be difficult for Sweden to achieve on its own (see section 2.1) as Reduced Climate Impact (1), Natural Acidification Only (3), a Non-toxic Environment (4), Zero Eutrophication (7) and a Balanced Marine Environment (10). This section assesses whether the PB framework and the indicators proposed in this report are useful for quantifying the legal competence deficit (*rådighet*) over the NEOs. Such estimates could provide guidance on which issues, policy areas and countries it would be important to focus on to in order to overcome the deficit.

The first step is to ensure that the definitions of the NEO and the relevant PB are sufficiently well matched in scope, scale and the level of target/boundary, so that the PB indicator and the related data proposed in chapter 4 can be used as a measure of countries' performance on the corresponding NEO.[21] The second step is to calculate Sweden's share of the amount by which the PB is being transgressed, in terms of emissions or resource use, to establish what part of the driver or pressure Swedish environmental law or policy could theoretically control. The remaining share constitutes the deficit, i.e., the part of the problem for which Sweden needs to seek international or bilateral cooperation to control.

However, our assessment is that this methodology is currently only directly applicable to one of the five NEOs listed above: Reduced Climate Impact. There is a direct match between this objective, which refers to the 2°C target, and the PB for climate change, given the coherence of the 2°C target and the boundary of 350 ppm CO_2 (see also footnote 12). Table 8 quantifies the deficit as over 99%, meaning that Sweden has no direct legal control over 99% of the emissions which threaten achievement of the NEO. Sweden is therefore fully dependent on international cooperation in order to achieve it. The major emitting countries, in absolute terms, that Sweden would have to work with are China, the U.S. and India (see Figure 10). However, if we consider which countries transgress their absolute boundaries the most, the top three are the U.S., China and the Russian Federation.

The main reason why the methodology does not work for other NEOs is the difficulty of the first step, i.e., matching the NEO and PB definitions in scope and scale. Of the five NEOs identified above as possessing a competence deficit, there is not yet a PB or related indicators for chemical pollution to match the NEO *a Non-Toxic Environment*. There is a partial match for *Natural Acidification Only* with the PB for ocean acidification. However, the acidification of oceans linked to CO_2 emissions is not mentioned under the NEO, which focuses on acidification of Swedish land and freshwater due to sulphur dioxide and nitrous oxide emissions, and the PB only addresses part of the problem that the NEO addresses.

There is some correspondence with the PB for nitrogen and phosphorus and *Zero Eutrophication* in terms of scope but whereas the scale of the former is global, the scale of the latter is national and regional, in particular the Baltic Sea region. This NEO is only concerned with those N and P releases, in water or air, which eventually risk causing eutrophication in Swedish or Baltic Sea waters – not all releases that risk causing a global anoxic event. Sweden's competence deficit in relation to the *global* transgression of the nitrogen PB can be estimated at over 99% (see Table 8), which means that there is little potential for Sweden to control the global use of nitrogen.

[21] Note that if the PB and the related indicator do not match the NEO definition, other indicators among the NEO indicators (see Annex I) may be available and reported on an international basis.

Table 8. Using PBs to quantify the Swedish competence deficit over selected NEOs and the effort needed to achieve the generational goal

Corresponding NEO/PB	PB process variable	Competence deficit[a]		PB vs. generational goal
		Swedish share of emissions trans-gressing PB [%]	Competence deficit [%]	Reductions required by Sweden to meet its downscaled PB [%]
Reduced Climate Impact – PB climate Change	CO_2	Consumptive: 0.37% Territorial: 0.18%	Consumptive: 99.63% Territorial: 99.82%	77% (reduction in consumptive emissions)
Zero Eutrophication – PB nitrogen[b]	N	Globally (territorial): 0.18% Regionally: 15%	Globally (territorial): 99.82% Regionally: 85%	71% (reduction of territorial emissions, larger reductions for a consumptive emissions)
A Balanced Marine Environment – PBs for nitrogen and phosphorus, chemical pollution, biodiversity (Key concerns include eutrophication, chemicals, and overfishing)	N	see above		see above
	Chemicals	Competence deficit: Lower pressure from Sweden than other countries, e.g., deposition of atmospheric mercury and waterborne cadmium (HELCOM 2010).		*Not yet quantified*
	Biodiversity loss	Competence deficit: the Swedish share of pressure on biodiversity compared to overall regional pressure is unclear.		*Not yet quantified. One proxy is protected areas that need to increase by 88% to meet Aichi target*[d]

[a] The method used to calculate the competence deficit consists of the following steps, as applied to *Reducing Climate Impact*. We establish the world's total emissions above the PB (16.6 $GtCO_2$/year). Sweden's emissions above our national boundary are 61.4 $MtCO_2$/year (consumptive) or 30.3 $MtCO_2$/year (territorial). Sweden's share of global emissions can then be calculated, in that 61.4 $MtCO_2$/year (consumptive) corresponds to 0.37% of total global emissions exceeding the boundary, and 30.3 $MtCO_2$/year (territorial) corresponds to 0.18%.

[b] Note that we only analyse nitrogen, as there is no downscaled boundary for phosphorous.

[d] Based on the data used in section 4. Sweden has protected 5.3% of it marine territorial areas and the Aichi target is 10%.

However, a more regional analysis is required. The targets of the Helsinki Commission (HELCOM) for maximum permissible nutrient inputs (in tonnes per year) to achieve "good environmental status" of the Baltic Sea could be seen as corresponding to the NEO on Zero Eutrophication. Focusing on nitrogen, the maximum allowable nitrogen input has been set at 601,720 tonnes per year (HELCOM 2012: 16). The total nitrogen load in 2006 was 836,100 tonnes (ibid.: 9). Sweden currently emits 15% of this amount, so it can be assumed that the same share holds for those emissions exceeding the maximum allowable input (135,000 tonnes). This would mean that, to the extent that the Swedish NEO means that the Baltic Sea should not risk being subject to eutrophication, there is a competence deficit of 85%. In other words, Sweden does not control 85% of the emission reductions needed to achieve its NEO.

Finally, *a Balanced Marine Environment* is an example of a highly comprehensive NEO, in that it addresses multiple problems facing marine environments, which have been organised into 11 separate issues (*preciseringar*) such as chemical status, ecological status, biodiversity, noise and cultural values. This objective is linked to a number of different PBs (see Figure 5). Hence, an assessment of the competence deficit would require a composite measure of several indicators, including the PBs on nitrogen and phosphorous as well as those on chemical pollution and loss of biodiversity. None of these have been quantified. Even if they hade, we would need to identify how to aggregate the different components. Table 8 provides some ideas but concludes that it is not possible to quantify the deficit for this NEO.

This report addresses the international dimension of Swedish environmental performance as a two-way interaction, and compares the quantified competence deficit on NEOs with the emission reductions needed for Sweden to be within the downscaled PBs. Table 8 (the right most column) gives the percentage reductions needed in order for Swedish per capita emissions to be within each PB.

This approach to quantifying the competence gap confirms that for the one NEO where a methodology was feasible, the gap is over 99%. This is to be expected for a small, low population country like Sweden. It makes it even more important to focus a considerable share of overall environmental policy efforts on how to leverage international cooperation, as opposed to a domestic focus. What has been examined above could be called “theoretical competence”, where actual competence would be determined by how well Sweden deploys its political and diplomatic skills and resources to influence those other actors which affect the Sweden’s NEOs. Thus, a large competence deficit should not be a reason to be passive.

The pilot of the approach described above suggests that it is fairly straightforward. However, the approach involves major scale issues, in that most of the NEOs are not expressed at the same global scale as the PBs, and there is a need to break down comprehensive objectives, including several problem areas, into more measurable variables. The extent to which PBs and NEOs directly match and can be used to measure each other is currently very limited. Could the PB framework be useful for informing an understanding of competence over NEOs in other ways? As a general backdrop, the picture of the Swedish share of current pressures on PBs is informative in that it shows that Sweden is either highly or completely dependent on international cooperation of various kind in order to reduce global environmental pressure, which will also make it difficult to achieve the NEOs.

5.3 Comparing other countries' performance and setting priorities for bilateral cooperation

So far, we have seen that Sweden has a significant environmental impact globally, especially when consumption measures are considered, but as a small country it is also dependent on the action taken by other countries. This section discusses and interprets the results for specific groups of countries. The goal is to provide input into priority setting for Swedish bilateral environmental cooperation, which will take into account many other factors in addition to performance on the PB indicators presented above. The groups of countries included here were selected by the Swedish EPA. Generally, countries are included due to their geopolitical importance, or because of the importance of maintaining or establishing bilateral collaboration with them on environmental and development issues.[22]

Brazil, the Russian Federation, India, Indonesia, and China (the BRIIC countries) are included due to their growing global economic and political importance. Turkey and Poland are added to this group because of their growing importance in the European context. Canada, Denmark, Finland, Iceland, Norway, the Russian Federation and the U.S. are selected because of their international collaboration through the Arctic Council. China, India, the Russian Federation, Georgia, Macedonia, Serbia, Ukraine and Belarus are included because of existing bilateral collaboration on environmental issues administered by the Swedish EPA. Finally, a number of countries are included that receive aid from the Swedish international development cooperation agency (Sida). These are all countries in priority group 1 (long term support for development) or priority group 3 (Countries in Eastern Europe supported to enable closer collaboration with the EU).

Figure 24 shows country performance for the four PBs for which we have developed national boundaries. For climate change, both consumptive and territorial measures are included as cooperation because countries' consumption patterns can have different implications to cooperation based on performance or production patterns (territorial performance). For example, focusing on consumptive performance implies that collaborations involve more awareness-raising among consumers and citizens than advice and technology transfers to producers. For freshwater and land use we show the consumptive measures but also include the boundaries on the aggregated national resource base. It should again be strongly emphasised that there are severe limitations with this methodology for the freshwater boundary, and even more so for the land use boundary on crop land. Countries have unique conditions, and the blunt use of a 15% boundary for cropland is too simplistic and does not take local conditions into account. However, we believe that this first attempt is still relevant for comparing relative performance between the different groups of countries.

[22] Note that in chapter 4 results were also reported for OECD countries.

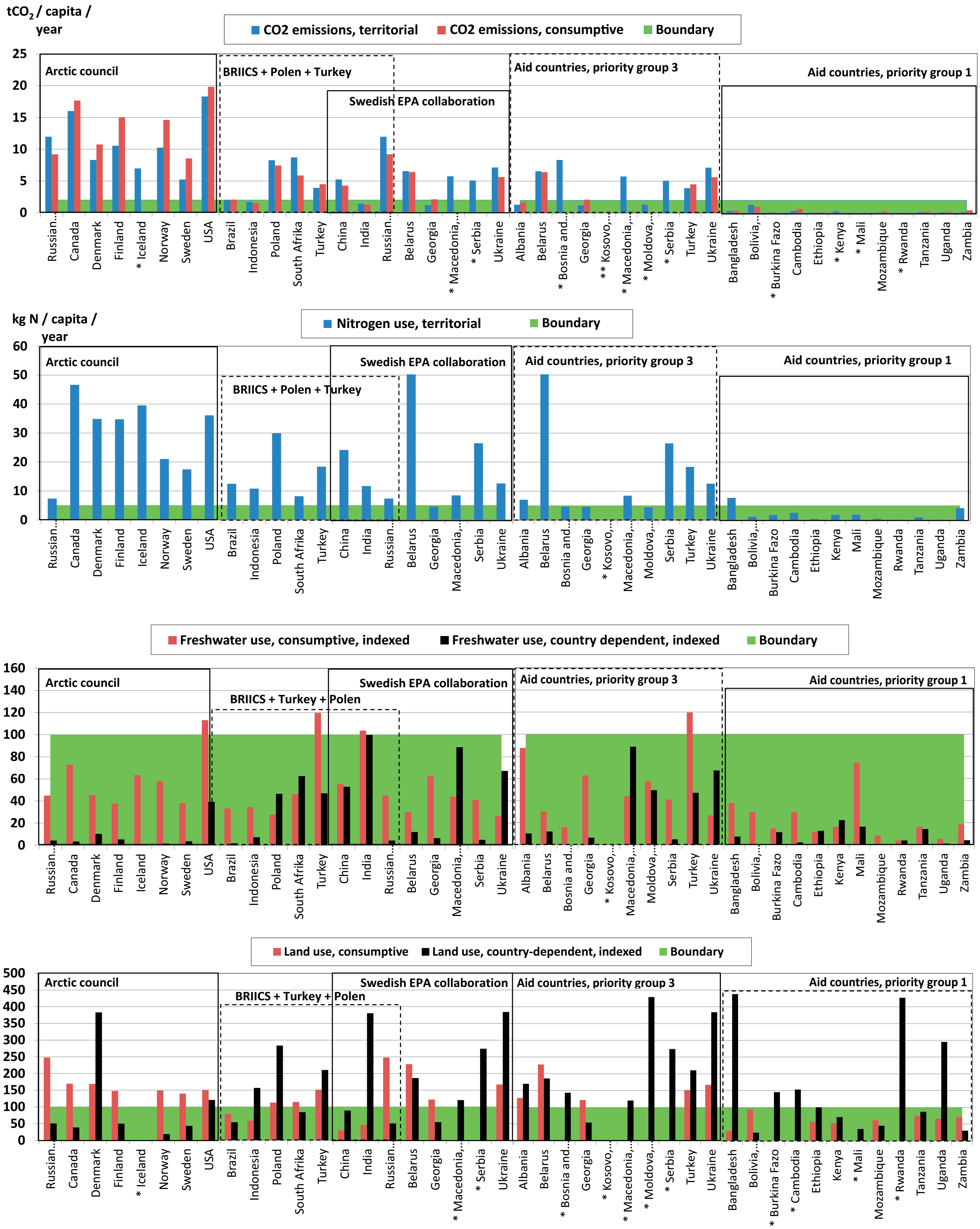

Figure 24. Comparing the performance of groups of countries on quantified national boundaries

For Freshwater and Land use, results are shown in relation to country-dependent boundaries (i.e., related to national resource base). Note that for nitrogen use, only the territorial performance is used. *No data for Kosovo, and data are lacking for consumptive performance on Climate Change and Land Use for Moldova, Serbia, Iceland and several of the countries in aid category 1 (see above).

Performance among the generally highly developed countries that are members of the Arctic Council is worse than the performance of less developed countries, including the BRIIC countries. Many highly developed countries transgress the climate change and nitrogen boundaries by several orders of magnitude. For the land use boundary, it is noteworthy that although the global boundary has not yet been transgressed (Rockström, 2009), high levels of consumption of land-intensive agricultural products in developed countries lead to transgressions of the per capita consumptive boundary. If all countries consumed agricultural products at the same rate as this set of highly developed countries, the global boundary on land use would already have been transgressed.

It is to be expected that countries with higher levels of economic development have higher consumptive use of land and water, and that they emit more CO_2 and use more nitrogen. Similarly, the countries in aid priority group 1, which are among the least developed in the world, have virtually no impact on the nitrogen or climate change boundaries. The consumptive measures of freshwater use and land use show similar patterns. It should again be emphasised that these countries have a right to develop and use a more proportionate share of the world's resources.

The BRIIC countries, the existing bilateral collaborations and aid priority group 3 belong to a category of countries that are between the more and the less developed groups in both climate change and nitrogen use. These group members are either approaching or already transgressing their national boundaries, but not to the same extent as is the case with the members of the Arctic Council. The picture, however, is a little different for land and water use. Consumptive measures of land and water use are about the same as those in the more developed countries, and for the country-dependent boundaries, relative to the national resource base, performance is on average worse than that of the members of the Arctic Council, probably because these countries tend to be located in more water-scarce regions.

Of the PBs which it was not possible to downscale to national boundaries, the trend for phosphorus use is similar to those for climate change, nitrogen and land use. Highly developed countries generally perform worse than, e.g., the BRIIC countries or the group of least developed countries in aid priority group 1. On ozone depletion, the indicator of territorial performance shows a rather different picture – the rapidly growing economies of the BRIIC countries are clearly ahead in their use of ODS. The pattern is less clear for biodiversity loss. There are some outliers (Iceland, Macedonia, Albania), which could be explained by their small population but high number of threatened species in unique environments (e.g., Iceland), and hence a proportionally worse per capita performance. Although it is more difficult to make connections between biodiversity loss and level of development, due to geography among many other things, Lenzen et al. (2012) illustrate that rich countries generally perform worse on the consumptive measure, i.e., they have a net negative impact abroad.

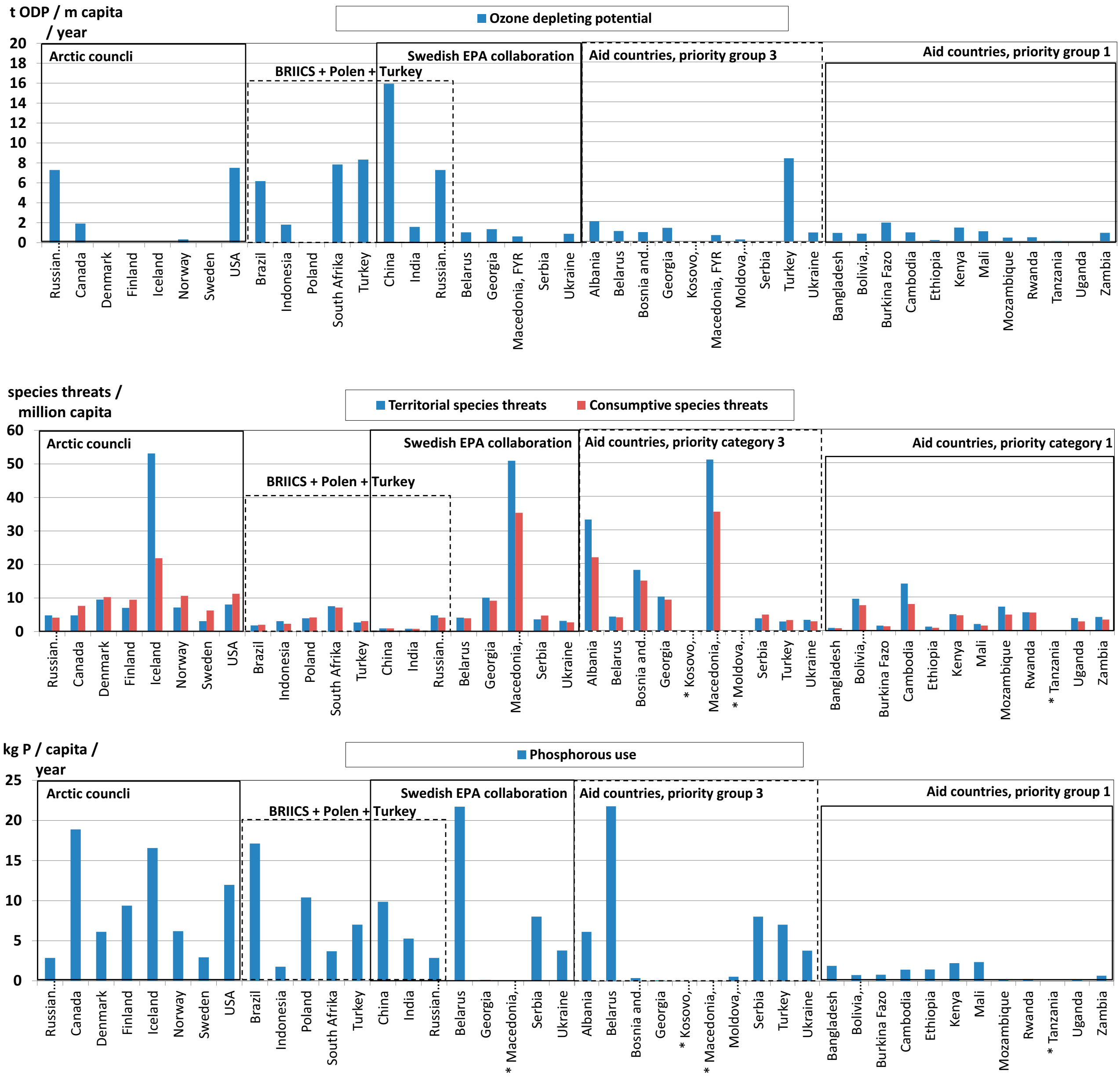

Figure 25. National performance of selected groups of countries on relevant indicators of problem areas as defined by the planetary boundaries

*No data for Kosovo. On Ozone, data are lacking for Serbia; on species threats, data are lacking for Modova; and on Phosphorous, use data are lacking for Macedoina and Tanzania.

Given that performance on PBs can be used as a criterion for prioritising bilateral partnerships, these results clearly highlight three broad categories of potential collaboration partners for Sweden. First, per capita performance is generally worse in the most highly developed countries and, here an important strategy will be to collaborate on how to reduce consumption pressures. Second, the BRIIC countries also have a high and growing impact on some measures and, given the size of these countries, it is important to help decouple both consumption and production patterns from high environmental impacts.

Third, the least developed countries in this sample have a low impact. As these countries have a right to develop, analysis of how to collaborate bilaterally with these countries must necessarily include both development and environmental concerns, but the downscaled PBs have limited value. The indicators developed in this report could be useful for selecting partner countries from within these broad groups. The choice between groups, however, will depend on Sweden's overall strategy.

Alternative indices and indicators should also be considered in the future use of these PB indicators. For example, the Environmental Performance Index contains response indicators on policy commitment and the effectiveness of countries. Such indicators can also be important in the selection of partner countries, both to inform the choice between more or less ambitious countries and to help focus capacity building efforts. The results presented in this section could also be considered for a wider group of countries than those reported here, in order to further contextualise the findings.

This point raises the question of whether the Swedish EPA should select priority countries for bilateral cooperation based on their performance on global problems alone. It might also be important to further cooperation with countries that face significant environmental challenges at the local and regional levels, as is already the case, e.g., the Baltic Sea and the Arctic, which may have second-order impacts globally or impacts of a non-environmental nature.

5.4 Comparing planetary boundaries and international environmental agreements

In addition to bilateral cooperation with key partner countries, Sweden also engages in international cooperation through a wide range of IEAs. By comparing the level of ambition and aspects of effectiveness of IEAs with the nine proposed PBs, we can assess possible gaps, both in terms of policy targets and successful implementation. This can help Sweden prioritise which IEAs and issue areas to focus its efforts on and attempt to advance internationally, to the extent that the PBs are taken as a reference point. This section compares existing IEAs and PBs. It should be emphasised that there are many voluntary, legally non-binding initiatives that, although not technically defined as IEAs, could well play an important role in international environmental problem-solving (e.g., the Climate and Clean Air Coalition). However, we focus on traditional legally binding IEAs. Furthermore, the assessment presented below focuses on "substantive IEAs" that more or less directly address PB control variables and specify targets. It does not review "procedural IEAs", such as the Aarhus Convention or the Espoo Convention, which regulate *how* environmental policy and management are to be carried out, e.g. through procedures such as environmental impact assessments. However, the indirect influence on environmental problem-solving through cooperation around procedures should not be underestimated. The harmonisation, learning and transparency-enhancing functions of such IEAs are seen by many as central to progressive environmental policy.

5.4.1 Initial assessment of the match between planetary boundaries and international environmental agreements

A number of sources were reviewed to identify and assess IEAs relevant to PBs: the *IEA Database* managed by the University of Oregon,[23] the *INFORMEA* database managed by UNEP[24] and publications from UNEP's *Global Environmental Goals* project (UNEP 2012def). Experts at the Swedish EPA and SRC/SEI were also consulted. The following review criteria guided the assessment:

- The existence of a relevant quantified target;
- coverage of the target (in terms of number of parties to the IEA and scope of targets in relation to the underlying problem);
- the level of ambition compared to the PB value;
- whether the IEA is legally binding;[25]
- whether a strong compliance mechanism exists; and
- achievement of targets (indicating successful implementation).

The results are presented in Annex III, with a short summary in Table 9. Table 10 collapses the criteria into three key aspects of compatibility. Note that it is not an assessment of how well regulated the issue area is as such. Instead, the assessment departs strictly from whether existing IEAs match with the particular PB proposed.

Among the seven quantified PBs and their control variables, we find that six are currently addressed in IEAs. Only ocean acidification has not yet been directly addressed,[26] but this is to be expected given that the risk of acidification is a relatively new scientific finding and that it would be most effectively addressed through reduced anthropogenic CO_2 emissions, which are already addressed by the UNFCCC (see also Kim, 2012). It can thus be concluded that the PBs are not new and have not been proposed in an international policy vacuum. Rather, they represent issues that have been addressed in some way in the large body of 900+ IEAs currently in force. At the same time, IEAs on specific environmental issues have sometimes been created for different reasons than why the same issue is included in the PB framework.

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[23] See http://iea.uoregon.edu/page.php?file=home.htm&query=static
[24] See http://www.informea.org/. The UN also hosts a central database on international treaties in various fields, see http://treaties.un.org/Pages/DB.aspx?path=DB/MTDSG/page1_en.xml
[25] Note that the status legally binding is unclear and more nuanced than a simple yes/no. It has been proposed that treaties are legally binding, but not necessarily the subsequent decisions taken under a treaty. This can be explained by the different procedural rules (unanimity vs. consensus decision-making) and requirements for ratification. Here, however, we simplify the assessment and classify all targets (whether set through treaties or decisions) as legally binding.
[26] Except for being mentioned in one of the CBD Aichi Targets (no. 10), see Annex III.

Table 9. Planetary boundaries and an assessment of relevant IEAs

Planetary boundary	Overall assessment	Comment
Climate change	++	While the UNFCCC has a compatible level of ambition (2°C target), the Kyoto Protocol and current pledges for a future agreement have failed to meet this level. The Kyoto Protocol will probably be successfully implemented, but it will not lead to the achievement of the UNFCCC objective.
Ocean acidification	–	No specific IEA in place, but the key policy measure would be to limit anthropogenic CO_2 emissions, thus the issue is indirectly addressed by the UNFCCC.
Stratospheric ozone depletion	+++	Relevant and quantified targets have been set through the 1987 Montreal Protocol, and they have high coverage and a higher level of ambition than the PB. The targets are legally binding and there is a clear compliance mechanism. The Protocol has been successfully implemented, with the exception of the undesirable climate effects of substitute substances and illegal trade.
Atmospheric aerosol loading	n/a	PB *tbd*, no comparison possible. Note that the WHO has issued a global particulates guideline and there are several regional IEAs on particulates concentrations and emissions, but these are primarily based on health concerns rather than environment and climate concerns.
Biogeochemical flows: nitrogen cycle and phosphorus cycle	(+)	No IEA with global coverage exists, but there are various regional agreements to reduce nutrient inputs to regional seas. Legal status and the extent to which these agreements include quantified targets vary. It is likely that the combined level of ambition, where expressed quantitatively, is significantly lower than the PBs.
Freshwater use	(+)	Until early 2013, no IEA with potential global coverage existed. It is unclear how many existing bilateral and multilateral agreements on transboundary waters include targets on water extraction as opposed to pollution reduction. Extraction from national waters is not regulated by any IEA.
Land use change	+	The Aichi Targets under UNCBD indirectly address (part of) the PB by specifying targets for protected areas and reduction of habitat loss. Their level of ambition in relation to the PB is unclear and it there appears to be no strong compliance mechanism.
Rate of biodiversity loss	++	The Aichi Targets under UNCBD directly or indirectly address aspects of the PB by specifying targets for extinction rates and habitat loss. The level of ambition is moderate to very high, but success in implementing previous similar targets has been limited and there is a lack of hard commitments stipulating how the targets will be achieved.
Chemical pollution	n/a	PB *tbd*, no comparison possible. Note that several relevant IEAs exist (e.g., on hazardous waste, POPs and heavy metals), but they do not yet cover all chemical substances of potential global/planetary concern.

Note: '–'= not addressed; '+' = relevant IEA exists; '++' = relevant IEA exists with compatible level of ambition; '+++' = relevant and compatible IEA successfully implemented.

For example, particulates (as atmospheric aerosols) have been addressed because of their human health effects rather than their environmental and climate effects, and phosphorus emissions for their local eutrophication effect rather than to prevent a global anoxic event[27].

Note that Table 10 primarily shows the extent to which PBs have been *addressed* – not successful goal achievement. Our review suggests that only the PB for stratospheric ozone depletion has been successfully dealt with in terms of the achievement of (adequate) goals. This is consistent with the finding in UNEP's Global Environmental Goals project, where lead in gasoline and the supply of safe drinking water were added to the list of successfully achieved goals (UNEP 2012e). Common to all three of these issues is that there are direct and clear human health effects, as opposed to more environmentally mediated effects on human well-being.

Several factors limit the extent to which the proposed PBs are actually matched by IEAs. First, the PBs for biogeochemical flows and freshwater use have not been addressed at the global level, as global level problems. Regional agreements exist, but it is unlikely that their combined ambition matches that of the PBs. Second, in relation to the PBs for biodiversity loss and land use change, targets have been defined but they are either not associated with clear and hard commitments for parties, or they focus on more qualitative aspects than quantified goals. Third, in the case of the PB for climate change, the UNFCCC contains a target with a comparable level of ambition (2°C), but the parties have not so far managed to translate this into adequate concrete emission reduction agreements. The Kyoto Protocol has too limited coverage in terms of Annex B Parties and the level of ambition is too low. Nor do the pledges made so far for a future climate agreement add up to the 2°C target embraced in decisions under the Convention.

Finally, further research is required on many of the IEAs that address the PBs mentioned above to establish whether implementation has been successful. It is likely that in many cases it has not been, or that the IEA target years are still ahead of us. The past track record in some cases suggests that successful implementation will be challenging, for example, of targets to reduce biodiversity loss. The success story commonly raised for IEAs, the Montreal Protocol to control ozone-depleting substances, is a success story also in regard of matching the PB. The PB for ozone depletion was actually transgressed in the 1980s, but this trend was reversed and the latest measurement shows that we are again below the PB (Rockström et al., 2009b). However, it will still take time for the stratospheric ozone layer to fully recover from human pressures and a key substitute for ozone depleting substances, HFCs, has turned out to be a potent greenhouse gas. This example shows the importance of considering all the PBs together when devising policy responses, to avoid problem shifting across boundaries (Nilsson and Persson, 2012).

[27] Oceanic anoxic events occur when oceans become completely depleted of oxygen below the surface levels. No such events have happened for millions of years, but geological records show they have happened many times in the past and they have been associated with mass extinctions.

What conclusions can be drawn from the assessment in Table 10 (and Annex 3), in terms of which IEAs and issue areas Sweden should prioritise? First, *ozone depletion* appears to have been relatively successfully dealt with and can therefore be seen as a lower priority issue. Second, the frameworks and the infrastructure are clearly in place for *climate change* and *biodiversity loss*, but Sweden could push for even tougher action and commitments by countries in order to reach the policy targets already agreed. Given their scope and their knock-on effects on other issue areas, such as ocean acidification, and IEAs, continued engagement with the UNFCCC and CBD would be a high priority. Third, the planetary effects of *land use change* and *freshwater use* highlighted by the respective PBs are clearly not recognised or regulated in existing IEAs. Sweden could lobby for greater awareness, but agreeing any regulatory or burden-sharing approaches is likely to be challenging given that national sovereignty is traditionally seen to apply strongly to land and water resources. Furthermore, land use change is clearly a cross-sectoral issue, which suggests that it would need to be addressed under several different IEAs. Finally, there is possibly greater scope for future international regulation of *nitrogen and phosphorus* consumption, given that they are specific substances that can more easily be controlled and that scientific studies have suggested that global yield gains can be made by reallocating fertiliser application (see Mueller et al., 2012). Since the PBs for chemical pollution and atmospheric aerosols have not yet been defined, we do not comment on priorities for Swedish engagement in the related IEAs, but this should not to be interpreted as suggesting that chemical pollution should be given lower priority in Swedish international environmental policy work.

5.4.2 Distinguishing between policy gaps and implementation gaps

A follow-up question in cases where relevant IEAs are in place is whether the transgression of PBs (as shown in Figure 1 and Table 1), i.e., the distance between the boundary and actual performance, represents a *policy gap* or an *implementation gap*, and whether those gaps can be quantified. By policy gap, we mean the difference between the proposed PB boundary value and the level of the comparable IEA target, where such a target exists. By implementation gap, we mean the difference between the IEA target and actual global performance. We thus look at actual performance and the PB value and ask whether the problem is low ambitions in international policy, or unsuccessful implementation of ambitious policy. Figure 26 illustrates the two gaps in a hypothetical case when a PB is transgressed. Table 10 presents the preliminary results of such an analysis.

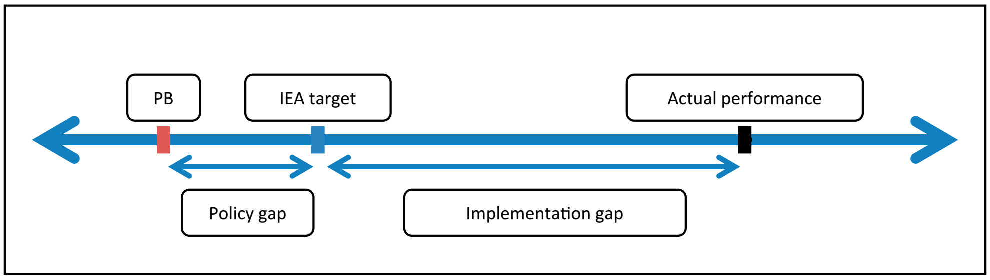

Figure 26. Illustration of policy gap vs. implementation gap

Table 10. Preliminary estimates of policy vs. implementation gaps for quantified PBs

Planetary boundary	Policy gap	Comment	Implementation gap	Comment
Climate change	0–1.3°C	– Both the PB and the UNFCCC refer to the 2°C target (i.e. zero policy gap). However, if 2°C target is taken to mean 450 ppm CO_2eq, this may be less ambitious than the PB (350 ppm CO_2) – Current pledges for a future agreement amount to a 3.3°C increase in temperature, i.e. causing a policy gap of 1.3°C (Climate Action Tracker)	2.0°C	– We are currently on a 4°C trajectory for 2100 (World Bank 2012), which exceeds the policy target by 2°C
Ocean acidification	0.15	– No target or policy set, so full policy gap.		– No target or policy set to be implemented.
Stratospheric ozone depletion	Negative gap (At least –7 DU)	– The PB is less ambitious than the current state of ozone layer under the current policy regime (i.e. a negative gap)	Negative gap (At least –7 DU)	–Further increase in negative implementation gap can be expected when ODS phase-out fully implemented.
Biogeochemical flows: nitrogen cycle and phosphorus cycle	Probably large	– Existing regional targets not yet aggregated to global level.	Unknown	– Requires research into implementation of existing but incomplete regional IEAs.
Freshwater use	Probably large	– Existing extraction provisions of many bilateral and regional IEAs not yet aggregated to global level.	Unknown	– Requires research into implementation of existing but incomplete regional IEAs.
Land use change	3.3 percentage points	– No target or policy set, so full policy gap. Aichi Target no. 10, that the 83% of land area that does not need to be protected could be converted to cropland, could be assumed to imply but if so this would represent a very big policy gap.		– No target or policy set to be implemented.
Rate of biodiversity loss	No gap	– Assuming that Aichi Target no. 10, to prevent the extinction of known threatened species, corresponds to the PB, there is no policy gap.	>100 E/MSY	– Current estimated extinction rate far exceeds the zero (or natural background extinction) target.
Atmospheric aerosols	*Not analysed here since PB not yet defined or quantified.*			
Chemical pollution	Not analysed here since PB not yet defined or quantified.			

Note: Cells in red in the left-hand column indicate which planetary boundaries have been transgressed so far. Cells in red in those rows mark whether it is *mainly* a question of a policy gap vs an implementation gap, or both.

Above all, this exercise demonstrates the difficulties and many assumptions involved in assessing gaps, and it should just be seen as a first attempt. In further gap analysis, results should be presented more pictorially.

Nonetheless, these initial estimates of policy vs. implementation gaps suggest that the potential implementation gap for *climate change* is currently more significant than the policy gap, although the latter is also large. Considering it was found that the UNFCCC target (2°C) corresponds to the PB (350 ppm CO_2), there is no or a minor policy gap. Considering that it has been estimated that the world is on 4°C path, though, the implementation gap is larger (at 2°C). For *ocean acidification*, there is a total policy gap, since no target has yet been formulated. For *ozone depletion*, on the other hand, there is a negative policy gap, since the PB is less ambitious than what has been achieved under the current policy regime. The negative implementation gap can be expected to grow when the phase-out and bans take effect and the ozone layer has had time to recover.

For the *biogeochemical cycles* and *freshwater use* PBs, the global aggregate of regional policy targets is not yet known, preventing easy gap analyses for these variables. On *land use change*, there is no direct target addressing permissible conversion to cropland, and consequently there is a complete policy gap. For *biodiversity loss*, finally, the highly ambitious Aichi Target no. 10 to prevent extinction of known species means that there is no policy gap, while poor implementation of the current and previous highly aspirational targets explains the transgression of this PB.

Gap analyses of this kind can be useful in order to properly diagnose problems of inadequate policy and/or implementation. They could be performed for a wider range of policy targets in the future, including those not agreed on outside of legally binding IEAs. They also help to raise the question of whether the policy targets encompassed within IEAs are the right ones to start with. Do they frame the problem in the most appropriate way? Do they make the problem manageable? It has been suggested that, for example, the targets in the Montreal Protocol were formulated in more manageable ways than those in the UNFCCC and the Kyoto Protocol. It has also been suggested that the focus on a temperature target and emission reduction quotas could be replaced by more action-oriented goals, such as the removal of fossil fuel subsidies or energy efficiency targets.

5.4.3 International environmental agreements are only one tool

When considering how well matched the proposed PBs are with existing policy responses, it should be emphasised that IEAs may be neither a necessary nor a sufficient approach in many cases. Instead, it has been argued that the PBs should be considered in a multi-level governance context, i.e. also at the national and the local levels (Nilsson and Persson 2012). In some cases, legal competence to act on a PB still largely sits with national bodies, and major conceptual and governance changes would be required to impose global IEAs, e.g., in the field of land use change or of freshwater extraction. Land area and water resources differ considerably across countries, and a country like Brazil can achieve much more for a PB than a combination of smaller countries could do together. Furthermore, there may be positive incentives to act unilaterally on some PBs, if they provide direct local benefits separate from global benefits. For example, local action on atmospheric aerosols can improve local air quality in addition to reducing regional and global problems. Local benefits may also be of a non-environmental kind. For example, some municipalities experience direct gains in terms of competitiveness and reputational effects from proactive climate policies.

In addition to legally binding IEAs, alternative tools to ensure international cooperation to reduce the pressure on PBs include voluntary approaches and capacity building efforts. Voluntary approaches have made great strides since the Rio summit in 1992 and the Johannesburg summit in 2002. In particular under the climate regime, a plethora of voluntary initiatives work in parallel with the UNFCCC, such as the Major Economies Forum, the Climate and Clean Air Coalition, city-based partnerships and the Carbon Disclosure Project for the private sector. While there is enthusiasm for their potential to mobilise, there is as yet little evidence of genuine effects on emission reductions, though.

A potentially effective way to deal with implementation gaps under current IEAs would be to increase the capacity building efforts targeted at developing countries, in particular where these could have positive effects on poverty reduction too. The mapping of national performance on PBs among developing countries presented in chapter 4 could help guide the allocation of Swedish investment in such capacity-building.

5.4.4 International environmental issues not addressed by the planetary boundaries

A final question of relevance to comparing PBs and IEAs is whether the latter address international environmental issues not covered in the PB framework. This would suggest either that the PB framework is incomplete, or that those other issues where cooperation has been secured are built on a different rationale to the one underlying the PB framework. A review of the IEA databases and UNEP's publications on Global Environmental Goals suggests that a number of issues have so far been addressed by IEAs but are not incorporated into the PB framework:

- Transboundary air pollution (non-aerosols), including acidification effects (e.g., sulphur dioxide, nitrogen oxides, VOCs, ammonia)
- Fish stocks
- Marine pollution (oil spills, hazardous waste, dumping)
- Biosafety
- Desertification
- Tropical timber
- Nuclear safety
- Hazardous waste

These issue areas, and why they have not been incorporated into the PB framework, are not analysed in detail in this report. However, it is clear that several cannot be considered fundamental Earth system processes that determine the resilience of the planet in the same way as the currently proposed PBs. They are nevertheless important issues that still merit international cooperation and engagement by Sweden.

5.4.5 Summary

In sum, this comparison of PBs against existing IEAs suggests that the problems of transgressing PBs and limited progress on environmental performance are not really about low ambitions in target setting and policy. Instead, the analysis suggests that there are four important paths for future engagement with IEAs:

- *Reduce implementation deficits in relation to existing targets and commitments*, most notably deficits with regard to climate change, biodiversity loss and land use. The latter also suffers from a lack of more direct targets to address the problem that the PB is trying to capture.
- *Highlight the global scale and implications of problems currently being addressed regionally*, most notably, freshwater and biogeochemical cycles are dealt with through regional approaches that fail to consider the global picture.
- *Extend the rationale for action from human health effects to effects on ecological and Earth system resilience, but also connect the two* – in the field of aerosols we have seen significant and rapid progress when the problem relates directly to human health, but less so when it relates to environmental effects. Momentum for environmental policy initiatives might be increased if it is better connected to the implications for human well-being.
- *Pursue additional tools for international cooperation other than merely relying on formal IEAs* – numerous voluntary initiatives exist and capacity building efforts targeted at developing countries could be an effective way to reduce implementation deficits.

6 Conclusion

6.1 Key conclusions

This report tests and evaluates the relevance of developing national boundaries based on the PB framework in order to assess the relative and absolute performance of countries on the key global environmental challenges and support the work on the Swedish NEOs and their international dimension. We conclude that despite the many uncertainties in the original PB framework, and the methodological challenges discussed in this report, the approach is both useful and relevant. Developing per capita and absolute national boundaries to compare performance is a natural and necessary step in order to make the PB relevant for policymakers – and this report is a pioneer in this effort. We chose to stick strictly to the original PB definitions – even though this has some limitations which are discussed below – in order to address the policy questions identified in the Chapter 1.

In addition to developing downscaled boundaries for four of the originally proposed PBs and reporting the performance of 61 countries on these boundaries and other indicators, our overall finding was that the PB framework appears to be more useful for some policy questions than for others. It is most useful for measuring the generational goal and for informing the selection of countries with which Sweden should cooperate bilaterally. Limitations arise when attempting to use it to quantify the deficit in legal competence over the Swedish NEOs. Finally, an overall picture was achieved of possible priorities for the comparison of PBs and international environmental agreements, but more detailed work is needed.

The *first policy question* was to explore whether the PB framework can be used to identify and measure the extent to which **Swedish efforts to achieve domestic environmental objectives cause increased environmental and health problems beyond Sweden's borders**. Consumption-based indicators on performance were compiled for several boundaries, and we believe that these are **relevant for addressing and assessing the generational goal**, since they capture the environmental effects of the Swedish economy not just domestically but also abroad. These indicators draw on existing consumption-based analyses, which all apply similar input-output based methods. Since the introduction of the ecological footprint, which synthesises both land use and consumptive carbon emissions, more and more environmental problems have been described in terms of "consumption footprints" and more recent efforts have aimed to establish a family of footprints (Galli et al., 2012). Methods are developing rapidly in this field and a nitrogen consumption indicator is likely to be added to the footprint family soon, which so far includes land use, carbon, water and biodiversity. A key strength of a consumptive analysis is that, since the world economy is so globalised, it enables a fairer comparison than territorial emissions and use of global environmental resources.

The Swedish EPA also considers consumption-based indicators to be key tools for understanding how Sweden performs on the generational goal, although the need for further methodological development is recognised (Naturvårdsverket 2012bcd). We believe that the PB framework can contribute to existing work in two important ways:

i. it is a **comprehensive framework** that captures many major global environmental challenges, as opposed to a more data-driven and single-issue approach, and
ii. it establishes absolute (per capita) boundaries and therefore allows measurement of the absolute performance of countries rather than simply their relative performance.

Work to assess the environmental component of the generational goal would definitely benefit from developing indicators that track Sweden's contribution to the transgression of these key thresholds in global earth processes.

The *second policy question* was whether the PB framework and its indicators could help to characterise and quantify the Sweden's **legal competence deficit** in relation to some of its NEOs. A review of all the bar charts and graphs presented in chapters 4 and 5 suggests that Sweden's contribution to the PBs is in most cases minor in absolute terms. This means that Sweden's competence to hand over to the next generation a situation in which most environmental problems have been resolved is limited. The methodological approach piloted here **only allows a quantification of the deficit for one NEO**: Reduced Climate Impact. The deficit was over 99% at the global level. We found that it was a worthwhile analytical exercise and that the PB framework in general is amenable to visualising environmental challenges both in terms of numbers and graphically. However, the current PB framework cannot add much when it comes to more regional challenges, such as eutrophication of a regional sea or regional transboundary air pollution. A future revised PB framework with regional thresholds could, however, enable such analysis. Furthermore, it is important to distinguish between a theoretical lack of competence (i.e., that a significant amount of relevant emissions takes place within other jurisdictions) and an actual lack of competence, where the latter would address how existing competence is actually deployed. As a small country – with a consequently low level of absolute environmental pressure in global terms, despite its environmentally intensive lifestyle – Sweden needs to consider how it can effectively leverage its bargaining power.

In response to the *third policy question*, the analysis presented in this report can potentially be used to identify sets of countries with similar challenges, and can be used as **one source of information to inform discussions on priorities in bilateral environmental cooperation**. Interpretations based on this first analysis, however, should be made with care. In addition, results are more robust when comparing performance across several boundaries and for a group of countries, as opposed to focusing on individual boundaries and individual countries. Using the downscaled boundaries and indicators selected above, performance data were generated for 61 countries and some general performance patterns were identified. However, it was also recognised that the selection of priority countries for bilateral cooperation will necessarily involve many other considerations, such as political relations, the level of economic development, key Swedish leverage opportunities, and so on.

When comparing country performance, it is important to be aware that the alternative performance indicators presented for each PB (per capita vs. absolute; consumptive vs. territorial) indicate different things and may have implications for the nature of the bilateral cooperation developed and the general approach to cooperation. For example, **per capita performance** indicators capture differences in standards of living and address equity issues and the right to develop, i.e. the "fair share" of a given environmental resource for different countries given their historical responsibility, capacity and other variables. Countries with rapidly worsening per capita performance may be good candidates for "leap-frogging" through technology transfer, so that they can advance human and economic development while decoupling both from environmental pressures. On the other hand, sometimes the **absolute performance** of a country is relevant when considering whether cooperation with one or a few jurisdictions needs to be prioritised. It may be inefficient to spread resources in many small countries, if the environmental pressure is concentrated in absolute terms within only a few jurisdictions. As is mentioned above, measuring **territorial performance** may be useful for identifying places where production technologies need to be made more sustainable. Measuring **consumptive performance**, on the other hand, can be useful for identifying places where consumption patterns and attitudes can be influenced through bilateral cooperation.

Finally, with regard to our *fourth policy question*, the analysis of how well the PBs are matched with IEAs suggests that **IEAs are in place for all but one PB, but that their implementation has not been successful**. There is no lack of global environmental goals. Nor is their level of ambition found wanting, as UNEP finds in a recent report. The problem is rather the limited progress on existing goals. A detailed assessment of existing IEAs led to an effort to discriminate between the policy gap and the implementation gap for each PB. Preliminary results are presented above, but the analysis needs further work in order to avoid relying too heavily on strong assumptions. Overall, our analysis suggests that there are **four important paths for future engagement in IEAs and international cooperation more broadly**:

i. to reduce implementation deficits in relation to existing targets and commitments;
ii. to highlight the global scale and implications of problems currently being addressed regionally;
iii. to extend the rationale for acting from human health effects to effects on ecological and Earth system resilience, but also to connect the two; and

iv. to pursue other tools for international cooperation than merely relying on formal IEAs, such as voluntary initiatives (some of which involve non-state actors) and capacity building efforts targeted at developing countries to support their implementation of international agreements and targets.

Finally, it should be re-emphasised that international cooperation may not be either necessary or sufficient to reduce pressure on individual PBs. Not all of them represent global public goods that require burden-sharing arrangements, but several can probably be effectively addressed – and even have economic benefits – at the regional, national and local levels. PBs should therefore be seen as a **multi-level governance** issue, which raises another important point. The PB framework was not intended to be the top of a hierarchical framework of environmental boundaries or goals – i.e., a set of global goals that should be translated into regional, national and local goals. While such a hierarchical framework may appeal to some, we would argue that environmental problems and governance are more complex. There will be important environmental issues to deal with for countries and communities that are not currently covered by the PBs. The PBs represent one view of the most important environmental issues, and they have been identified on a particular basis: their significance for Earth system resilience and their risk of leading to harmful tipping points.

6.2 Methodological limitations and future work

This report suggests downscaled boundaries for four of the original nine planetary boundaries. There are a number of caveats with each suggested boundary, including uncertainty on data, limitations in the original control variables proposed and assumptions made when developing the method, such as selection of indicators (e.g., converting a state variable to a pressure or driver variable). Results should therefore be used with caution, in particular when comparing individual countries but also when describing which problem (or part thereof) is really "indicated" by an indicator.

The most problematic aspect of the method developed in this report is the assumptions made when downscaling those PBs which are **aggregated boundaries**, i.e., locally or regionally manifested processes with planetary-level implications when aggregated. Conditions of land and water availability and scarcity vary across countries, and applying the methods from the original paper to the national level in order to construct downscaled boundaries is problematic. However, we believe that developing consumption-based indicators on the relevant drivers, as identified in the DPSIR framework, provides the best way forward. This method can be used to downscale the global boundary to a per capita boundary, and the footprint of each country can be assessed against this common, universal boundary.

As is noted above, there may be reasons to tackle the **equity issue** by differentiating between per capita boundaries for rich and poor countries, in the short term at least, to take account of differences in the level of development and the right to develop. While equity has been long recognised with regard to climate change, more analysis should be undertaken of boundaries relating to nitrogen and phosphorus use, land use and freshwater use. Furthermore, the analysis presented above does not address the individual pathways for different countries to reach the ultimate per capita boundary. For example, how quickly should Sweden reduce its CO_2 emissions to get closer to the 2 t / per capita boundary? Future work could connect the above analysis more closely to various applications of so-called budget approaches, not only for climate change but also for various other boundaries.

For the aggregated boundaries, the impacts are also ultimately different in different countries, and the appropriate method for estimating national contributions to the transgression of each PB would be to assess the impact of, e.g., the consumptive use of nitrogen downstream in each country. The quality of national resources and their management differs greatly for land and freshwater. For example, one hectare of forest in a tropical rainforest country is more important to the resilience of the Earth system than one hectare of temperate forest. This suggests a need for differentiated boundaries in different regions to account for **quality aspects**, and future work on the downscaled indicators provided in this report should adjust for this. Similarly, water productivity affects how urgent national water scarcity is both domestically and globally. Indicators that address management practices would therefore be complementary to these PB indicators.

It is also important to emphasise that the **criticisms of the original boundary framework** also apply to the methods developed in this report. That is, some of the original boundaries, such as nitrogen fixation and land use, have been criticised for being arbitrary. Limiting biodiversity loss to an indicator of species extinction has also been sais to be too simplistic. It should, however, be emphasised that with the exception of the phosphorus boundary, no concrete suggestions for revised boundaries have been presented. The overall approach of developing quantified boundaries has received little criticism. As is described above, work is ongoing to develop a second, refined version of the framework, including a quantified chemical boundary and revised phosphorous and land use boundaries.[28] Finally, most of the indicators presented above build on publicly available data in databases provided by FAO and others. As these are based on data reported by countries, this introduces uncertainty because the willingness to report accurate data varies.

Although there are significant limitations to the methodology developed in this report, we believe that it is useful to try to develop quantified national and per capita boundaries based on the method outlined in the original framework. There are also **ways to reduce uncertainty**, for example, by comparing

[28] Personal communication with Will Steffen, November 2012

groups of countries for several variables at a time. Hence, as a first analysis of its kind, we believe that the method developed in this report shows promise, and indicates a path that needs to be further explored in order for PBs to gain traction. One option for future methodological work would be to provide data that **track changes in selected indicators over time**. Such an analysis would show the trajectories of different countries and would potentially be a powerful tool for identifying the most important countries to work with in order to improve the chances to avoiding a critical shift in the earth system.

We also tested an approach to analysing **policy and implementation gaps**. The methodology needs further development in terms of the consistency of the assumptions made. A particular problem arises when a PB is only partially addressed in a policy target. Graphical illustration of gaps would also be helpful.

A final caveat that should be emphasised when it comes to using the methodology and the above results to prioritise partner countries for environmental cooperation is the importance of considering **local environmental problems** and threats to local ecological resilience. The PB framework was developed to highlight and strengthen awareness about the planetary implications of various environmental processes and how they are affected by human pressure. It was not the aim to argue that only planetary problems are important. The PB framework should be seen as a complement to analyses of local or national environmental problems, which need to be addressed in their own right regardless of their lack of obvious planetary implications.

6.3 Recommendations and the need for future research

When using planetary boundaries as a basis for **comparing the performance of countries,** the main conclusion is that, in general, it is most important to work with developed countries and countries with rapidly growing economies. These countries have higher absolute and per capita impacts on the environment globally, and thus a bigger responsibility for progressive action on, e.g., mitigating climate change. In future work on the application of the methodology presented above, we recommend analysis that tracks the development of performance over time as this would enable the identification of countries with negative trends and fast rates of change in performance, while also exploring equity issues in more depth.

A further recommendation is that additional consumptive based indicators, covering each of the PBs, can be used to complement the existing indicators to **assess whether Sweden is meeting its generational goal**. The tentative methods and results on, e.g., consumptive land use and the threats to biodiversity driven by consumption provided in this report are concrete examples. Using the PB framework as a guide to selecting consumption-based indicators has the advantage of providing a more complete framework than a "datamining" approach. Ideally, in order to evaluate the achievement of the generational goal, we want to know what we are evaluating and why (i.e., the risk of globally irreversible effects) rather than being left with an ad hoc selection of indicators.

A third recommendation is that **Sweden must act more proactively and more strongly in negotiations around the IEAs if the competence deficit is to be reduced**. Many of the NEOs depend on international action, and the analysis of national performance presented above suggests that Sweden's performance is of minor importance in many cases. The review of IEAs shows that much of the legal infrastructure is in place to address PBs, but that the level of ambition and the effectiveness of implementation need to be strengthened. However, it should also be emphasised that legally binding IEAs would be only one of many routes to take. Sweden could expand bilateral cooperation with key countries (as is discussed above) to improve their domestic performance on key issues. Voluntary initiatives involving non-state actors could be pursued as an alternative to IEAs. Finally, a strategy could be pursued to identify the co-benefits of environmental action at the local level and, ultimately, at the global level. The new Climate and Clean Air Coalition, in which Sweden is a key player, embraces this approach.

The work presented in this report to downscale the proposed PBs and measure national performance on them is the first of its kind worldwide. Some lessons were learned from these efforts, which can inform future methodological development and future analyses:

- The PB definitions are likely to be revised, and future work needs to reflect the continuing work on PBs and adjust the methods presented in this report accordingly. In particular, the chemical pollution and aerosols boundaries have not yet been quantified. If this work is progressed, the possibility of corresponding national boundaries or additional relevant indicators could be explored.
- There are large uncertainties over the quality of data which are beyond the scope of this work to address. Future work should aim to quantify these uncertainties and to update the data used as potentially more accurate data and assessments become available.
- The development of time series that track performance over time would be a natural next step, which would enable interesting analyses of the development trajectories of different countries.
- The analysis of policy and implementation gaps in relation to each PB holds promise as an effective educational tool, but requires further methodological and pictorial development.

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Annex I

Swedish NEOs and environmental policy priorities

Sources: Regeringens proposition (2010), Miljödepartementet (2012) and www.miljomal.nu.

Overall generational goal, adopted by the Swedish Parliament in 2010

"The overall goal of Swedish environmental policy is to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental and health problems outside Sweden's borders."

"The generational goal means that the basic conditions for solving the environmental problems we face are to be achieved within one generation, and that environmental policy should be directed towards ensuring that:

- Ecosystems have recovered, or are on the way to recovery, and their long-term capacity to generate ecosystem services is assured.
- Biodiversity and the natural and cultural environment are conserved, promoted and used sustainably.
- Human health is subject to a minimum of adverse impacts from factors in the environment, at the same time as the positive impact of the environment on human health is promoted.
- Materials cycles are resource-efficient and as far as possible free from dangerous substances.
- Natural resources are managed sustainably.
- The share of renewable energy increases and use of energy is efficient, with minimal impact on the environment.
- Patterns of consumption of goods and services cause the least possible problems for the environment and human health."

16 national environmental quality objectives adopted by the Swedish Parliament in 1999 (target 1–15) and 2005 (target 16).

1. Reduced Climate Impact
2. Clean Air
3. Natural Acidification Only
4. A Non-toxic Environment
5. A Protective Ozone Layer
6. A Safe Radiation Environment
7. Zero Eutrophication
8. Flourishing Lakes and Streams
9. Good-Quality Groundwater
10. A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
11. Thriving Wetlands
12. Sustainable Forests
13. A Varied Agricultural Landscape
14. A Magnificent Mountain Landscape
15. A Good Built Environment
16. A Rich Diversity of Plant and Animal Life

Specifications for national environmental quality objectives (Sw. "preciseringar") adopted by the Government in 2012

Since 2010 the Government has been responsible for specifying each environmental quality objective in more precise quantitative or qualitative language, including targets or standards. These are not time-bound. The first specification was drawn up for each of the objectives in 2012.

Milestones in priority areas (Sw. "etappmål") adopted by the Government in 2012

Since 2010 the Government has been responsible for defining milestones in priority areas of environmental policy. These are not environmental quality objectives but refer to societal transitions and the interim steps towards reaching environmental quality objectives. In 2012, the first set of 13 milestones was announced covering four areas as well as greenhouse gas emissions.

- Greenhouse gas emissions
  - By 2020 Swedish GHG emissions, except those regulated under the EU ETS, should be reduced by 40% compared to 1990
- Air pollution
  - Limited emissions of transboundary air pollutants in Europe
  - Limited emissions of air pollutants from shipping
  - Limited emissions from small-scale wood fuel combustion
- Hazardous substances
  - Regulation of particularly hazardous substances
  - Knowledge about the environmental and health properties of substances
  - Information about hazardous substances in goods
- Waste
  - Improved resource management in food supply chains
  - Improved resource management in the construction sector
- Biological diversity
  - Ecosystem services and resilience
  - Values of biodiversity and ecosystem services
  - Threatened species and habitats
  - Invasive species
  - Knowledge about genetic diversity

Note that the Ministry of Environment has also announced that it will prioritise four environmental policy areas: reducing climate emissions, a non-toxic environment, the marine environment, and ecosystems and biodiversity.[29]

[29] See http://www.regeringen.se/sb/d/1471/a/162711

National indicators selected by relevant government authorities

A total of 112 national indicators associated with the 16 national environmental quality objectives are reported on the NEO website (www.miljomal.nu). These are listed in Swedish below.

Indikator	Ansvarig myndighet	Miljökvalitetsmål
Allergiframkallande kemiska produkter	Kemikalieinspektionen	*Giftfri miljö*
Allergiker/astmatiker och luftföroreningar	Socialstyrelsen	*Frisk luft*
Anlagda våtmarker	Naturvårdsverket	*Myllrande våtmarker*
Antal järvar i fjällen	Naturvårdsverket	*Storslagen fjällmiljö*
Antal renar i fjällområdet	Naturvårdsverket	*Storslagen fjällmiljö*
Antal skyddade våtmarker i myrskyddsplanen	Naturvårdsverket	*Myllrande våtmarker*
Antikvarisk kompetens	Länsstyrelserna i samverkan	*God bebyggd miljö*
Begränsat näringsläckage – fånggrödor	Länsstyrelserna i samverkan	*Ingen övergödning*
Begränsat näringsläckage – skyddszoner	Länsstyrelserna i samverkan	*Ingen övergödning*
Bensen i luft	Naturvårdsverket	*Frisk luft*
Besvär av bilavgaser	Socialstyrelsen	*Frisk luft*
Besvär av inomhusmiljön	Socialstyrelsen	*God bebyggd miljö*
Besvär av trafikbuller	Socialstyrelsen	*God bebyggd miljö*
Besvär av vedeldningsrök	Socialstyrelsen	*Frisk luft*
Beteenderelaterad UV-exponering	Strålsäkerhetsmyndigheten	*Säker strålmiljö*
Betesmarker	Jordbruksverket	*Ett rikt odlingslandskap*
Bostäder med fukt och mögel	Socialstyrelsen	*God bebyggd miljö*
Buller i fjällen	Länsstyrelserna i samverkan	*Storslagen fjällmiljö*
Byggnadsminnen	Boverket	*God bebyggd miljö*
Certifierade brunnsborrare	Sveriges geologiska undersökning	*Grundvatten av god kvalitet*
Cesium-137 i mjölk	Strålsäkerhetsmyndigheten	*Säker strålmiljö*
CMR-ämnen i varor	Kemikalieinspektionen	*Giftfri miljö*
Ekologisk animalieproduktion	Länsstyrelserna i samverkan	*Giftfri miljö*
Ekologisk mjölk	Länsstyrelserna i samverkan	*Giftfri miljö*
Ekologiskt odlad mark	Länsstyrelserna i samverkan	*Giftfri miljö*
Energianvändning	Naturvårdsverket	*Begränsad klimatpåverkan*
Exploatering i fjällen	Länsstyrelserna i samverkan	*Storslagen fjällmiljö*
Exponering för miljötobaksrök	Socialstyrelsen	*God bebyggd miljö*
Fiskefartyg	Länsstyrelserna i samverkan	*Hav i balans samt levande kust och skärgård*
Fjällrävsföryngringar	Länsstyrelserna i samverkan	*Begränsad klimatpåverkan*
Fosfor i havet	Havs- och vattenmyndigheten	*Ingen övergödning*
Förorenade områden	Länsstyrelserna i samverkan	*Giftfri miljö*
Försurad skogsmark	Naturvårdsverket	*Bara naturlig försurning*
Försurade sjöar	Naturvårdsverket	*Bara naturlig försurning*
Föryngring av flodpärlmussla	Länsstyrelserna i samverkan	*Levande sjöar och vattendrag*

Indikator	Ansvarig myndighet	Miljökvalitetsmål
Gammal skog	Skogsstyrelsen	*Levande skogar*
Grusanvändning	Boverket	*Grundvatten av god kvalitet*
Grustäkt i grundvattenområden	Sveriges geologiska undersökning	*Grundvatten av god kvalitet*
Hudcancerfall – malignt melanom	Strålsäkerhetsmyndigheten	*Säker strålmiljö*
Hudcancerfall – tumör i huden, ej malignt melanom	Strålsäkerhetsmyndigheten	*Säker strålmiljö*
Hushållsavfall	Naturvårdsverket	*God bebyggd miljö*
Hård död ved	Skogsstyrelsen	*Levande skogar*
Häckande fåglar	Länsstyrelserna i samverkan	*Ett rikt växt- och djurliv*
Häckande fåglar i fjällen	Länsstyrelserna i samverkan	*Storslagen fjällmiljö*
Häckande fåglar i odlingslandskapet	Länsstyrelserna i samverkan	*Ett rikt odlingslandskap*
Häckande fåglar i skogen	Länsstyrelserna i samverkan	*Levande skogar*
Häckande fåglar i våtmarker	Länsstyrelserna i samverkan	*Myllrande våtmarker*
Häckande fåglar vid vatten	Länsstyrelserna i samverkan	*Levande sjöar och vattendrag*
Hälsofarliga kemiska produkter	Kemikalieinspektionen	*Giftfri miljö*
Klimat och häckande fåglar	Länsstyrelserna i samverkan	*Begränsad klimatpåverkan*
Klimatpåverkande utsläpp	Naturvårdsverket	*Begränsad klimatpåverkan*
Klorid i grundvattnet	Sveriges geologiska undersökning	*Grundvatten av god kvalitet*
Konsumenttillgängliga kemiska produkter	Kemikalieinspektionen	*Giftfri miljö*
Kulturspår i åkermark	Jordbruksverket	*Ett rikt odlingslandskap*
Kväve i havet	Havs- och vattenmyndigheten	*Ingen övergödning*
Kvävedioxid i luft	Naturvårdsverket	*Frisk luft*
Kväveoxidutsläpp	Naturvårdsverket	*Bara naturlig försurning*
Körsträcka med bil	Länsstyrelserna i samverkan	*Begränsad klimatpåverkan*
Marknära ozon i luft	Naturvårdsverket	*Frisk luft*
Miljöföroreningar i modersmjölk	Kemikalieinspektionen	*Giftfri miljö*
Miljöledningssystem	Länsstyrelserna i samverkan	*Giftfri miljö*
Nationella utsläpp av CFC	Naturvårdsverket	*Skyddande ozonskikt*
Nedbrytning av arkeologiskt material i jord	Riksantikvarieämbetet	*Bara naturlig försurning*
Nedfall av kväve	Naturvårdsverket	*Bara naturlig försurning*
Nedfall av svavel	Naturvårdsverket	*Bara naturlig försurning*
Nickelallergi	Socialstyrelsen	*Giftfri miljö*
Oljeutsläpp till havet	Havs- och vattenmyndigheten	*Hav i balans samt levande kust och skärgård*
Partiklar PM10 i luft	Naturvårdsverket	*Frisk luft*
Planering energi	Länsstyrelserna i samverkan	*God bebyggd miljö*
Planering grönstruktur och vattenområden	Länsstyrelserna i samverkan	*God bebyggd miljö*
Planering kulturmiljö	Länsstyrelserna i samverkan	*God bebyggd miljö*
Planering transporter	Länsstyrelserna i samverkan	*God bebyggd miljö*
Påverkan på runinskrifter	Riksantikvarieämbetet	*Frisk luft*
q-märkt	Länsstyrelserna i samverkan	*God bebyggd miljö*
Radon i dricksvatten	Länsstyrelserna i samverkan	*God bebyggd miljö*

Indikator	Ansvarig myndighet	Miljökvalitetsmål
Radon i flerbostadshus	Länsstyrelserna i samverkan	*God bebyggd miljö*
Radon i skolor	Länsstyrelserna i samverkan	*God bebyggd miljö*
Radon i småhus	Länsstyrelserna i samverkan	*God bebyggd miljö*
Rivningsförbud	Boverket	*God bebyggd miljö*
Skadade forn- och kulturlämningar	Riksantikvarieämbetet	*Levande skogar*
Skydd av skogsmark – naturreservat	Skogsstyrelsen	*Levande skogar*
Skydd av våtmarker	Länsstyrelserna i samverkan	*Myllrande våtmarker*
Skyddad areal skogsmark – biotopskyddsområden	Skogsstyrelsen	*Levande skogar*
Skyddad areal skogsmark – naturvårdsavtal	Skogsstyrelsen	*Levande skogar*
Skyddade fjällmiljöer	Naturvårdsverket	*Storslagen fjällmiljö*
Skyddade sjöar och vattendrag	Havs- och vattenmyndigheten	*Levande sjöar och vattendrag*
Slåtterängar	Jordbruksverket	*Ett rikt odlingslandskap*
Strandnära byggande vid havet	Havs- och vattenmyndigheten	*Hav i balans samt levande kust och skärgård*
Strandnära byggande vid sjöar och vattendrag	Havs- och vattenmyndigheten	*Levande sjöar och vattendrag*
Strålnivå i omgivningen	Strålsäkerhetsmyndigheten	*Säker strålmiljö*
Svaveldioxid i luft	Naturvårdsverket	*Frisk luft*
Svaveldioxidutsläpp	Naturvårdsverket	*Bara naturlig försurning*
Sömnstörda av trafikbuller	Socialstyrelsen	*God bebyggd miljö*
Terrängskotrar som uppfyller bullerkrav	Naturvårdsverket	*Storslagen fjällmiljö*
Tillförsel av fosfor till kusten	Havs- och vattenmyndigheten	*Ingen övergödning*
Tillförsel av kväve till kusten	Havs- och vattenmyndigheten	*Ingen övergödning*
Utsläpp av flyktiga organiska ämnen	Naturvårdsverket	*Frisk luft*
Utsläpp av PM2,5	Länsstyrelserna i samverkan	*Frisk luft*
UV-strålning	Naturvårdsverket	*Skyddande ozonskikt*
Vattenskyddsområden	Sveriges geologiska undersökning	*Grundvatten av god kvalitet*
Vindkraftsel	Länsstyrelserna i samverkan	*God bebyggd miljö*
Vägsaltanvändning	Sveriges geologiska undersökning	*Grundvatten av god kvalitet*
Växtskyddsmedel	Kemikalieinspektionen	*Giftfri miljö*
Växtskyddsmedel i ytvatten	Kemikalieinspektionen	*Giftfri miljö*
Yrkesfiske	Länsstyrelserna i samverkan	*Hav i balans samt levande kust och skärgård*
Åkermark	Jordbruksverket	*Ett rikt odlingslandskap*
Återvinning Glas	Länsstyrelserna i samverkan	*God bebyggd miljö*
Återvinning Metall	Länsstyrelserna i samverkan	*God bebyggd miljö*
Återvinning Pappersförpackningar	Länsstyrelserna i samverkan	*God bebyggd miljö*
Återvinning Plast	Länsstyrelserna i samverkan	*God bebyggd miljö*
Äldre lövrik skog	Skogsstyrelsen	*Levande skogar*

Annex II

Recent developments in the planetary boundaries framework: summary of the scientific debate

Summary of new developments on the definition of planetary boundaries

Revision of PBs	**New developments**
Phosphorus cycle	Carpenter and Bennett (2011) argue that the original phosphorus (P) boundary only addressed the risk of anoxic events in world oceans and not eutrophication of freshwater. Even current P flows to the oceans, which are three times higher than pre-industrial levels, are associated with extensive eutrophication of freshwater. They propose a new set of boundaries for freshwater and find that global flows exceed the new boundaries, including flows calculated at a more conservative level. Consideration is also being given to how to make the nitrogen cycle boundary more place-sensitive.
Biodiversity loss	The current boundary variable, the species extinction rate, embeds the recognition that every loss to the Earth's "genetic library" introduces new risks for ecosystem integrity, but it is not a sensitive measure in terms of threshold changes. At an expert discussion workshop convened by the Stockholm Resilience Centre, Diversitas and the UK Royal Society, it was proposed that the control variable should be linked more explicitly to ecosystem function, perhaps through the identification of "critical biomes". This analysis is under way.
Land use change	This boundary is being reconsidered by the Stockholm Resilience Centre in order to more directly reflect forest loss and make it more place-sensitive. A biome approach is being tested in an attempt to reflect the fact that different types of forest have different carbon storage capacities and albedo effects, and hence different climate feedback effects.
Chemical pollution	Under the auspices of ITM at Stockholm University, a group of chemists have started analysing how a PB or multiple PBs could be defined. This work will not be finalised in time for the present report.
New candidate PBs	**New developments**
Global terrestrial NPP	Running (2012) has proposed global terrestrial net primary (plant) production (NPP) as a measurable PB for the biosphere. A specific boundary level is not defined per se, but it is noted that humans now appropriate 38% of NPP. Of the remaining NPP, it is estimated that 53% is not harvestable. The sustainability question is therefore when humanity will 'hit the roof' of NPP, given current estimates of population growth.
"Plastic soup"	The accumulation of particulate waste in the Pacific Ocean is suggested by Lewis (2012) as a relevant global environmental problem to be solved internationally, but is not associated with a preindustrial Holocene 'safe' level.

The scientific and policy debate on planetary boundaries

This report does not evaluate the scientific legitimacy of the PB framework, but merely notes that the scientific debate on the PB framework is evolving. A majority of scientific commentary appears to support the concept of PBs,[30] with some exceptions (Lewis 2012; Nordhaus et al. 2012; Brook et al. 2013). Specific definitions proposed in the 2009 article have also been questioned. Johan Rockström responded to some recent critiques and misunderstandings in June 2012.[31]

Nor is it possible here to evaluate the political legitimacy of the PB concept and framework, i.e. whether it constitutes a broadly acceptable basis for political decision-making. However, in addition to being referred to in various high-level reports by international governmental organisations, such as the UN, the OECD and the EU, the concept of PBs was also referred to at one point in the negotiating text leading up to the Rio+20 conference. It was not included in the final outcome document, due, inter alia, to concerns among developing countries that it implies imposing constraints on their right to develop. A high-impact elaboration of the PB framework, with a clear policy objective and a clear focus on the sustainable development agenda, is the "doughnut" put forward by the NGO Oxfam (Raworth 2012). Oxfam suggests that definitions of minimum socio-economic floors are also needed, meaning that the "safe operating space" is conceived as a doughnut shape and it would be unsafe to transgress these minimum socio-economic standards. The debate about whether the PB framework is an appropriate way to frame environmental sustainability challenges at the global level will continue in relation to the process for defining Sustainable Development Goals, which was a core outcome of Rio+20 (see e.g., Griggs et al., 2013; Rockström et al., 2013).

[30] See e.g., commentaries published in the same issue of Nature as the original PB article (http://www.nature.com/news/specials/planetaryboundaries/index.html) and commentaries published in the Scientific American in 2010 (http://www.scientificamerican.com/article.cfm?id=boundaries-for-a-healthy-planet). See also a summary of support and critiques published in The Economist 16 June 2012 (http://www.economist.com/node/21556897). Our review of scientific articles citing the Rockström et al. (2009) suggests that the PB framework is referred to as a reference framework in a majority of them, and is not fundamentally questioned.

[31] See http://www.stockholmresilience.org/research/researchnews/addressingsomekeymisconceptions.5.5d9ea857137d8960d471296.html

Annex III

Planetary boundaries and relevant IEAs

The table below identifies relevant IEAs for each planetary boundary and assesses their compatibility. The following aspects have been reviewed for each relevant IEA: the existence of a relevant quantified target; the coverage of the target (both in terms of the number of Parties to the IEA and the scope of the targets in relation to the underlying problem); its level of ambition compared to the PB value; whether the IEA is legally binding; whether a strong compliance mechanism exists; and achievement of targets (indicating successful implementation). It should be emphasised that this review only includes quantified targets, and not qualitative targets and aspirations (e.g., that forests should be sustainably managed). Finally, this review only includes intergovernmental environmental agreements subject to signature and ratification by national governments/parliaments, and not voluntary initiatives or those involving non-state actors.

Planetary Boundaries			**Relevant IEAs**	**Compatibility of PB and IEA provisions/targets**	**Comment**
Earth system process	Proposed parameter and boundary	Current status (year)*			
Climate change	Atmospheric CO_2 concentration not above 350 ppm	393.81 ppm CO_2	Framework Convention on Climate Change (1992), UNFCCC	• Relevant quantified target (2°Celsius temperature rise) – • High coverage • Compatible level of ambition, with some reservations • Legally binding • No compliance mechanism • Target not achieved so far	*Note that for reasons of clarity, we assess individually the treaty text, the Kyoto Protocol and current pledges for a future agreement. Table 10 considers the UNFCCC regime as a whole.* The objective of the UNFCCC is "*stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*" (art. 2), but no quantified targets are specified in the Convention text. Recognising scientific findings, Parties have interpreted this as meaning **2°C** and have also committed to review this target in respect of a 1.5°C rise. Decision 1/CP.16 (the Cancun Agreements) states that the Parties: "*Further recognises* that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above preindustrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity; *also recognises* the need to consider, in the context of the first review, as referred to in paragraph 138 below, strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5°C". The 2°C was first adopted by the EU in 1996 as a policy target and subsequently adopted in the Copenhagen Accord in 2009, which fed into the Cancun Agreements.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
					• The 2°C target can be considered **a relevant and quantified target** compared to the PB. Models have established a relationship between atmospheric CO_2 concentrations and temperature rise, although significant uncertainty applies and normative assumptions are required regarding acceptable probability levels. • This target has **high coverage**, both in the sense of its scope (temperature change is a key impact parameter of CO_2 concentration) and its support among countries. It has 194 Parties. • The **level of ambition** of the 2°C target is compatible with the PB. According to the IPCC, stabilisation at 450 ppm CO_2eq is associated with a 2.1°C temperature rise (best guess); 450 ppm CO_2eq is comparable with 350 ppm CO_2 (see IPCC, SYR: 67, table 5.1). However, 450 ppm CO_2e involves significant risk that the 2°C target will not be achieved. Therefore, 400 ppm CO_2e has been recommended by the Swedish Scientific Council for Climate (Miljövårdsberedningens rapport 2007:3: 12). It has also been suggested that ppm CO_2 can be converted to ppm CO_2eq by adding 50 as a rule of thumb. Thus, we conclude that 350 ppm CO_2 offers a good chance of staying below 2°C (see also Hansen et al. 2008), and possibly better so than 450 ppm CO_2e. However, the key question is of course when CO_2 concentration will be stabilised and whether it will be in time to limit temperature rise to 2°C. Since the UNFCCC does not specify the urgency of the 2°C target or set timebound action targets, this reduces the level of ambition. • The UNFCCC is **legally binding** for the Parties that have ratified it. • However, there is **no compliance mechanism** for the commitments made in the Convention or the decisions taken by the COP. • Successful implementation of the UNFCCC can be evaluated in different ways and using different criteria. However, given that it has not yet led to a reversal of GHG emission trends or a globally binding agreement (except for the partial Kyoto Protocol), it is here considered **unsuccessful in its implementation**.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
			Kyoto Protocol (1997) (first commitment period ends 2012; second commitment period 2013–2017/2020)	• Relevant quantified targets (CO_2e emission reductions) • Low coverage • Significantly lower level of ambition • Legally binding • No strong compliance mechanism • (Likely) achievement of target	Annex B Parties that ratified the Kyoto Protocol (first commitment period) committed to reducing their total CO_2e emissions by 4.2% below their 1990 levels by 2008–2012. (If the US had ratified, the figure would be 5.2%). This reduction corresponds to 0.59 Gt, which can be compared with global emissions in 2008 which amounted to 30.3 Gt (Peters et al. 2011). The second commitment period is currently being negotiated. Some high emitters have decided not to sign up for a second period (Canada, Japan, Russia). Economy-wide emission reduction targets have so far been announced by Australia, Croatia, New Zealand, Norway, Kazakhstan, Switzerland, Belarus, Iceland, Nauru, Liechtenstein, Ukraine and the EU (see http://unfccc.int/resource/docs/2012/awg17/eng/misc01.pdf, http://unfccc.int/resource/docs/2012/awg17/eng/misc01a01.pdf , http://unfccc.int/resource/docs/2012/awg17/eng/misc01a02.pdf) . These are supposed to be converted to QELROs for COP18. • The Kyoto Protocol national reduction commitments can be considered **highly relevant and quantified** targets in relation to the PB. • The **coverage** of the commitments can be considered poor, given that only 38 countries have made commitments (and only 37 countries ratified) and that the total reduction commitment (0.59 Gt) amounts to only 2% of total global emissions (as of 2008). The Kyoto Protocol thus addresses only a small part of the overall GHG emissions problem. • The **level of ambition** can also be considered low, as indicated by the poor coverage. Furthermore, it has been estimated that through flexible mechanisms a large surplus of assigned amount units (AAUs) has been created, which under current rules can be taken forward to the second commitment period (see http://carbonmarketwatch.org/wp-content/uploads/2012/11/AAU-banking-briefing-paper-Point-Carbon.pdf) . • The emission reduction commitments in the Kyoto Protocol are **legally binding**. • The **compliance mechanism** states that failure to comply would oblige the Party to achieve the reduction in the next commitment period plus an additional 30% reduction. However, this mechanism can be considered weak, since a second commitment period is still uncertain and Parties can and have withdrawn from the first commitment period. A stronger compliance mechanism in practice might be blocking eligible Parties from utilising flexible mechanisms. This has been imposed in cases of non-compliance with reporting requirements. • Regarding implementation of commitments in the first period, data are not yet available up to and including 2012. However, a compilation of the fifth National Communications in 2011 showed that emissions in Annex I countries (US included) had decreased by 6% in the period 1990–2008 (see http://unfccc.int/resource/docs/2011/sbi/eng/inf01.pdf). If this level is maintained or improved until 2012, the Kyoto Protocol emission reduction target will be **successfully implemented**.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
			(Voluntary) pledges for a future agreement	• Relevant quantified targets • Medium coverage • Significantly lower level of ambition • Not legally binding (yet) • Unclear if there will be any compliance mechanism • Targets not set as agreement not yet made (expected 2015)	Starting with the 2009 Copenhagen Accord, developed and developing countries have made pledges as an input to negotiations on a 2015 agreement of unknown legal status. The Climate Action Tracker online tool (http://climateactiontracker.org/) has compiled all the pledges and analysed them in relation to the 2 degree target and various global emission trajectories. • Targets of various kinds have been pledged, including for emission intensity and emission reductions. They are **relevant and quantified** in relation to the PB. • The **coverage** in terms of countries is higher than for the Kyoto Protocol second commitment period, and includes high and growing emitters such as the BASIC countries (in total 29 countries plus the EU27). • The current Climate Action Tracker analysis (September 2012) estimates that pledges under the most likely scenario will result in warming of 3.3°C with a 68% confidence interval of 2.6–4.1°C, which means a **lower level of ambition** than the PB.
	Change in radiative forcing limited to +1 W m^{-2}	+1.87 W m^{-2}	**None** (impact parameter).		
Ocean acidification	Global mean saturation state of aragonite in surface sea water not below 2.75	2.90	**None** (impact parameter).		General comments: • A key policy recommendation in the scientific literature is to stabilise atmospheric CO_2 concentration, addressed under climate change agreements. More research, monitoring and indicators are also recommended. Finally, it has been recommended to reduce land-based sources of pollution that contribute to lowering pH in coastal and ocean waters and to reduce inputs of nitrogen and sulphur oxides and ammonium compounds that contribute to lowering pH in coastal and ocean waters. • Aichi Target no. 10 under the UN Convention on Biological Diversity (CBD) states that: "By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimised, so as to maintain their integrity and functioning". However, it is not clear what measures should be taken under the CBD in particular to achieve this target. • For governance initiatives by NGOs and scientists in relation to ocean acidification, see the 2008 Honolulu Declaration on Ocean Acidification and Reef Management http://coralreef.noaa.gov/aboutcrcp/strategy/reprioritization/wgroups/resources/climate/resources/oa_honolulu.pdf and the 2008 Monaco Declaration http://www.ocean-acidification.net/Symposium2008/MonacoDeclaration.pdf • A proposal to consider ocean acidification under the UNFCCC http://oceana.org/sites/default/files/Climate_change_and_Ocean_acidifciation_-_Synergies_and_opportunities_under_the_UNFCCC_Dec_2_0_0.pdf

Planetary Boundaries			**Relevant IEAs**	**Compatibility of PB and IEA provisions/targets**	**Comment**
Stratospheric ozone depletion	Concentration of ozone no less than 276 DU	283 DU	Montreal Protocol on Substances that Deplete the Ozone Layer (1987), under the Vienna Convention for the Protection of the Ozone Layer (1985)	• Relevant quantified targets (phase-out targets and bans) • High coverage • Higher level of ambition • Legally binding • Strong non-compliance mechanism • Promising achievement of targets	The Montreal Protocol entered into force in 1989 and has since undergone several revisions. Several ODS are controlled under the agreement, including CFCs, HCFCs, halons and methyl bromide. CFC consumption and production was banned in developed countries in the 1990s and the use of HCFCs is to be reduced from 2015. • The bans and phase-out management plans can be considered **relevant and quantified** targets in relation to the PB. • The **coverage** of the agreement is high, with 197 Parties. However, one of the substitute substances, HFC, has been found to be a potent greenhouse gas, which means that the scope of the agreement has not yet included negative side-effects on other internationally agreed environmental goals (climate change in this case). • The **level of ambition** compared with the PB can be seen as higher. The PB has not been transgressed so far and it can be expected that if the Montreal Protocol is adhered to, further improvements of the stratospheric ozone layer will follow and full recovery will be achieved by 2050 (see http://science.nasa.gov/science-news/science-at-nasa/2006/26may_ozone/) . • The Montreal Protocol is **legally binding**. • There is a detailed **non-compliance procedure**, where trade sanctions with respect to ODS and products containing CFCs are one of the strongest responses (see art. 8, Decisions II/5, IV/5 and X/10). • The ozone layer has been found to be recovering and the Montreal Protocol is generally seen as a success story, with relatively rapid and broad agreement on phase-out (including agreement across developed and developing countries) and **initial recovery of the ozone layer**. However, there have also been reports on smuggling of ODS and the potency of HFCs as a greenhouse gas remains an unsolved problem.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere on a regional basis, boundary **TBD**	TBD	**None**	No global IEA and no PB to be compared with. It should be noted that the international guideline for particulates concentration and the regional agreements on emission reductions that exist have so far been motivated from health concerns primarily, rather than environmental concerns (including positive and negative climate effects).	General comments: • WHO has set international guidelines on the concentration of air pollutants, based on the health effects only. The guidelines for particulate matter is for i) PM2.5 10 μg/m3 as annual mean and 25 μg/m3 as 24-hour mean and ii) PM10 20 μg/m3 as annual mean and 50 μg/m3 as 24-hour mean (see WHO Air Quality Guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide, Global update 2005, http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf). • There is no global agreement to limit air pollution, but there are various regional initiatives. • In Europe (and North America), there is a legally binding IEA and EU regulation both with quantified limit values or emission ceilings: – The 1979 Convention on Long-Range Transboundary Air Pollution has led to eight protocols addressing air pollution, including the setting of national emissions ceilings for pollutants such as sulphur, nitrogen oxides, VOCs and ammonia, and regulating heavy metals and POPs. There are 51 Parties, mainly the UNECE region and the U.S. and Canada. In May 2012, the 1999 Gothenburg Protocol was revised to incorporate emission ceilings for particulates. – In the EU, two directives set limit values for the concentration of particulates, primarily based on human health concerns. Directive 2008/50/EC on ambient air quality and cleaner air for Europe states that for PM10 a limit value of 40 μg/m3 shall not be exceeded (annual mean) and 50 μg/m3 shall be exceeded (as a one-day average) on a maximum of 35 times per calendar year. It also specifies an exposure concentration obligation for PM2.5 at maximum 20 μg/m3 by 2015. Depending on initial levels of PM2.5 concentration, percentage reduction targets also apply to countries. Directive 2004/107/EC sets target values for arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons as fractions of PM10. The WHO guidelines are thus more ambitious than the EU limit values. • There are several cooperation initiatives in Asia but we did not identify quantified emission or concentration limits or targets, in e.g. the 1998 Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia, the Joint Forum on Atmospheric Environmental Issues in Asia and the Pacific (2009), Clean Air Asia (2001), ASEAN Agreement on Transboundary Haze Pollution (2002), Asian Co-Benefits Partnership (2010). • There are several cooperation initiatives in Africa, but we did not identify quantified emission or concentration limits or targets, e.g. the Air Pollution Information Network for Africa (1997), the Eastern Africa Regional Framework Agreement on Air Pollution (Nairobi Agreement-2008), West and Central Africa Regional Framework Agreement on Air Pollution (Abidjan Agreement-2009), Southern African Development Community (SADC) Regional Policy Framework on Air Pollution (Lusaka Agreement – 2008) • In Latin America and the Caribbean, we did not identify agreements with quantified emission or concentration limits or targets but an Intergovernmental Network on Air pollution has been established and has held consultations around a Framework Agreement on air pollution and climate change.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
Biogeochemical flows: nitrogen cycle and phosphorus cycle	– Amount of N2 removed from the atmosphere for human use, no more than 35 million tonnes per year – Quantity of P flowing into the oceans, no more than 11 million tonnes per year	– 121 Mt – 8.5–9.5 Mt	None	No global IEA that the PBs can be readily compared with. There are various regional agreements, but they differ in the extent to which they define relevant and quantified targets and in the extent to which they are legally binding. It is also relevant to consider the extent to which airborne nitrogen pollution is regulated in IEAs.	General comments: • **UNEP's Regional Seas Programme** has been operating since 1974 and now comprises 13 regional seas across the globe, with the participation of 143 countries (http://www.unep.org/regionalseas/default.asp). Six of them are administered directly by UNEP. There are an additional 5 partner programmes (for the Antarctic, Arctic, Baltic Sea, Caspian Sea and North-East Atlantic). The 13 Regional Seas programmes function through an Action Plan, in 12 cases underpinned by a legal framework such as a Convention and associated Protocols. Four of the 13 Regional Seas programmes include specific protocols or action plans for land-based sources of pollution, including nutrients. However, the extent to which they include quantified targets, are legally binding and are successfully implemented requires more research. • An early programme in the Regional Seas programme was the1976 Convention for the Protection of the **Mediterranean Sea** against Pollution (Barcelona Convention), with the 1980 (revised in 1996) Protocol on pollution from land-based sources and activities. The Protocol includes nutrients and eutrophication to be addressed in action plans, but does not specify quantified targets. • In the **Baltic Sea region**, the 1992 Convention on the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention), governed by the Baltic Marine Environment Protection Commission (Helsinki Commission, HELCOM), replaced the previous 1974 Convention to reflect changes in the region (www.helcom.fi). It has seven country Parties and the EU. It specifies nitrogen and phosphorus as harmful substances and sets out Best Environmental Practices to be followed nationally to prevent nutrient pollution from agriculture (Annex III). In addition to this legally binding convention, a series of ministerial declarations have been made, including a commitment in 1988 to reduce nutrient discharges by 50% by 1995. The Baltic Sea Joint Comprehensive Environmental Action Programme (1992–2012) further defined a number of pollution hotspots in the region and investments were made in some of these, reducing pollution as a result. The Baltic Sea Action Plan was adopted by HELCOM in 2007. It is based on objectives for good ecological status by 2021. An overall target of reducing nutrient inputs into the Baltic Sea to an annual amount of max 21,000 tonnes of phosphorus and 600,000 tonnes of nitrogen is proposed, which has been translated into provisional country-wise annual nutrient input reduction targets for the Parties. By 2010, Parties should have developed national programmes to achieve these targets. The provisional targets are expected to become permanent targets through decisions at the next Ministerial meeting in 2013. Under HELCOM, there are thus relevant and quantified targets for the specific region addressed. Their level of ambition compared to the global PBs is difficult to assess. They appear not to be legally binding and no compliance mechanism is referred to, although there is political agreement around them.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
					• In the **North East Atlantic region**, the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention), governed by the OSPAR Commission, replaced the previous 1972 Convention focused on dumping and subsequently also on pollution from land-based sources. It has 15 country Parties and the EU. It covers several environmental pollution problems, including eutrophication. Annex I provides for the Commission to draw up programmes and measures for the reduction of inputs of nutrients. However, so far no quantitative targets have been set. The 2010 North-East Atlantic Environment Strategy sets the objective of minimising eutrophication and making sure it is a non-problem area by 2020. It further specifies that: (i) by 2011, the OSPAR Commission will quantify the reduction of nutrients in the maritime area required for individual eutrophication problem areas to achieve non-problem area status; (ii) by 2012, identify and quantify the main contributing sources to individual eutrophication problem areas and river basins, including transboundary nutrient loads; and (iii) by 2013, implement a revised reporting system for nutrients which coordinates data collection on sources, pathways and environmental status. Unlike HELCOM, there are not yet quantified targets. It is unclear whether any targets defined will be legally binding. • In the **EU**, a number of EU Directives address nutrients and eutrophication problems, including the Marine Strategy Framework Directive, the Water Framework Directive, the Nitrates Directive, the Urban Waste Water Treatment Directive, and the Integrated Pollution Prevention and Control Directive. • In addition to the above initiatives, pollution from excess nutrients has been given attention under the CBD. Aichi Target no. 8 states that: "By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity". However, it is not clear what measures should be taken under the CBD in particular to achieve this target.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
Global freshwater use	Consumption of freshwater by humans no higher than 4,000 km3 per year	2,600	None	Many (150+) bilateral and multilateral agreements regulating transboundary water resources with potential relevance to the PB. An IEA on transboundary watercourses with more global coverage is now emerging.	General comments: • The 1992 **Convention on the Protection and Use of Transboundary Watercourses and International Lakes** (the UNECE Water Convention) currently has 39 Parties in the UNECE region. It was amended in 2003 to allow accession by all UN member states and from February 2013 it will be open for such accession. It could thus potentially become a global IEA. The focus is on water pollution, but some provisions also appear to address water quantity, and thereby to be relevant to the PB. Article 2.2 stipulates that "The Parties shall, in particular, take all appropriate measures: (a) To prevent, control and reduce pollution of waters causing or likely to cause transboundary impact; (b) To ensure that transboundary waters are used with the aim of ecologically sound and rational water management, conservation of water resources and environmental protection; (c) To ensure that transboundary waters are used in a reasonable and equitable way, taking into particular account their transboundary character, in the case of activities which cause or are likely to cause transboundary impact; (d) To ensure conservation and, where necessary, restoration of ecosystems." There are currently more than 150 bilateral and multilateral agreements and arrangements in the UNECE region under the Convention. The extent to which these agreements contain relevant and quantified targets at a compatible level of ambition, how much of the global water resource they cover in combination, and whether they are legally binding and being successfully implemented requires further research. • The IEA database hosted by the University of Oregon reports 106 agreements across the globe on freshwater resources.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
Land-system change	Percentage of global land cover converted to cropland no more than 15% *Note that current revision of this PB is likely to make it more focused on the extent of forested area and qualify it with respect to certain biomes/ regions.*	11.7%	**Convention on Biological Diversity** (1992)	• Quantified targets but of partial relevance • High coverage • Unclear level of ambition in relation to PB, requires further research • Legally binding • No strong compliance mechanism • Too early to assess achievement of targets	The tenth Conference of the Parties in 2010 adopted a Strategic Plan for Biodiversity (2011–2020) (see http://www.cbd.int/decision/cop/?id=12268). The mission of the Strategic Plan is to take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being and poverty eradication. A set of 20 targets, the **Aichi Targets**, was adopted, including the following which are most relevant to the PB for land use: – By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced (target 5); – By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes (target 11); – By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable (target 14); – By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification (target 15). Note that Aichi Target no. 7 addresses sustainable management of agricultural land and forests, but this relates more to the quality aspects of land rather than quantities of land.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
					• The **relevance, coverage and level of ambition** of these targets to the PB is questionable. – Target 5 does not specify a sub-target for forests specifically regarding rate of loss of the natural habitat they provide. – Target 11 specifies that 17% of terrestrial areas and inland waters should be protected areas or subject to other effective area-based conservation measures. Presumably such status would protect them from conversion to cropland. – Target 14 is highly ambitious if interpreted as that all forested areas provide essential services, and would in effect ban deforestation and presumably ensure that the PB is not transgressed. – Target 15 is also open to interpretation regarding what share of "degraded ecosystems" is constituted by degraded forest ecosystems. • The CBD is a **legally binding** agreement. • There is **no strong compliance mechanism** under the CBD, merely a general reporting requirement (art. 26). • The Aichi Targets are new and 2020 as the target year provides some time for **implementation,** so it as yet uncertain whether quantified targets will be achieved. The 2010 BIP Indicator reported that in 2008, 12.2% of terrestrial land was protected and 5.9% of marine areas (http://www.wdpa.org/resources/statistics/2010BIP_Factsheet_Coverage_of_Protected_Areas.pdf).
			Other relevant IEAs		• The **UNFCCC** does not specify any targets for deforestation but addresses the issue in several ways (see The Rio Conventions Action on Forests, 2012, http://unfccc.int/resource/docs/publications/rio_20_forests_brochure.pdf) : – REDD (Reducing emissions from deforestation and forest degradation) – Since the eleventh session of the conference of the Parties good progress has been made in developing methodological guidance, identifying essential elements, principles and safeguards and considering financing options for implementing REDD-plus at the national level. – LULUCF (Land use, land-use change and forestry) – Developed country Parties to the Kyoto Protocol report and account for their greenhouse gas emissions by sources and removals by sinks for the LULUCF sector as part of their annual accounting of greenhouse gas inventories under the UNFCCC. For the first commitment period of the Kyoto Protocol (2008–2012), Parties had the option of electing to report and account for emissions and removals from the following land use activities: forest management, cropland management, grazing land management and revegetation. For the second commitment period, reporting and accounting for emissions and removals from forest management is mandatory. – Afforestation and reforestation project activities under the Clean Development Mechanism – In the first commitment period of the Kyoto Protocol, reforestation and afforestation projects located in developing country Parties are eligible for crediting under the CDM.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
Rate of biodiversity loss	Extinction rate no higher than 10 species per million species per year	>100	**Convention on Biological Diversity** (1992)	• Quantified targets on relevant parameters • High coverage • Moderate level of ambition • Legally binding • No strong compliance mechanism • Unsuccessful implementation of previous target for biodiversity loss	• The **United Nations Convention to Combat Desertification** does not specify quantified targets, but several national action plans developed under it have reported on national targets. The Tenth Conference of the Parties in 2010 the adopted a Strategic Plan for Biodiversity (2011–2020) (see http://www.cbd.int/decision/cop/?id=12268) . The mission of the Strategic Plan is to take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. A set of twenty targets, the **Aichi Targets**, was adopted, including the following which are most **relevant** to the PB and (explicitly or implicitly) **quantified**: – "By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced" (target 5) – To assess relevance for the PB in its current formulation would require connecting habitat loss with resulting species extinction. There is relevant scientific evidence to make this connection at a general level, but it is scientifically and computationally difficult to quantify the non-linear and complex relationship. – "By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes" (target 11) – Similar to the previous target, the relevance of this target to the PB depends on how easily species extinction can be connected to size of areas protected, as well as properties of the particular areas selected. – "By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained" (target 12) – This target is highly relevant and compatible with the PB in level of ambition, but refers only to known species. • The Aichi Targets can be considered to have **high coverage** in that the CBD has 193 Parties and the targets encompass terrestrial, aquatic and marine biodiversity. • The **level of ambition** of the Aichi Targets in relation to the PB can be considered moderate to high, especially for the first and third target cited above. Regarding the second, recent statistics on coverage of protected areas from UNEP-WCMC suggest that this target is moderately ambitious. The third is highly ambitious but limited to known species. The overall mission of the Strategic Plan (see above) is highly ambitious, more so than the PB. However, it comes with no hard commitments on how Parties will ensure its achievement in the timeframe given. • The CBD is a **legally binding** agreement.

Planetary Boundaries			Relevant IEAs	Compatibility of PB and IEA provisions/targets	Comment
					• There is **no strong compliance mechanism** under CBD, merely a general reporting requirement (art. 26). • Regarding **implementation** of CBD to date, the 2010 target set in 2002 to achieve a significant reduction in the current rate of biodiversity loss at the global, regional and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth is considered not to have been met, at least not at the global level, in the 2010 Strategic Plan. Prospects for successful implementation of the 2020 Aichi Targets are therefore challenging.
			Other biodiversity-related IEAs		Note that there are other biodiversity-related IEAs, but the CBD is the predominant framework agreement. See the 2000 Cartagena and 2010 Nagoya Protocols under the CBD, the 1979 Convention on Migratory Species (Bonn Convention), the 1973 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), the 2001 International Treaty on Plant Genetic Resources, and the 1971 Convention on Wetlands of International Importance (Ramsar Convention)).
Chemical pollution	TBD	TBD	Many potentially relevant IEAs		General comments: • In the chemical management field, there are several relevant IEAs which have high coverage in terms of Parties, some of which specify bans or other quantified targets, e.g. the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, the 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs) and the Protocol on Heavy Metals (both under CLRTAP), and the 2001 Stockholm Convention on Persistent Organic Pollutants. In addition, there is a global voluntary agreement open for both UN member states and non-state actors: the 2006 Strategic Approach to International Chemicals Management. Negotiations are also ongoing on a global legally binding instrument on mercury (expected to be opened for signature in 2013). At the same time, there are several key chemicals and aspects of chemical management that are not internationally regulated.

*For data sources, see the references section and/or hyperlinks in the text.

National Environmental Performance on Planetary Boundaries

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A study for the Swedish Environmental Protection Agency

Swedish environmental policy establishes that the environmental efforts should focus on the 16 national environmental quality objectives. Sweden is exposed to environmental impacts from other countries which affect Sweden´s ability to achieve these environmental quality objectives. At the same time, Swedish consumption and production have an impact on environmental performance in other countries. The overall Swedish environmental policy, the so-called generational goal, specifies that efforts to resolve Swedish environmental problems should not be at the expense of environmental and health problems occurring in other countries.

This study was commissioned by the Swedish Environmental Protection Agency and carried out by the Stockholm Resilience Centre and the Stockholm Environment Institute. The purpose is to test whether the concept of *planetary boundaries* (PBs), as defined by Rockström et al. (2009ab), in different ways could reflect the international dimension of Sweden's national environmental quality objectives.

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