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Research article

Analysing the impacts of air quality policies on ecosystem services; a case study for Telemark, Norway

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ABSTRACT

There is an increasing interest in considering the effects of air pollution on ecosystem services supply in order to enhance cost-benefit analyses of air pollution policies. This paper presents a generic, conceptual approach that can be used to link atmospheric deposition of air pollutants to ecosystem services supply and societal benefits. The approach is applied in a case study in the Telemark county of Norway. First, we examine the potential effects of four European air quality policy scenarios on N deposition in the ecosystems of this county. Second, we analyse the subsequent impacts on the supply of three ecosystem services: carbon sequestration, timber production and biodiversity. Changes in the supply of the first two services are analysed in both physical and monetary units, biodiversity effects are only analysed in physical terms. The scenarios derive from work conducted in the context of the European National Emissions Ceilings Directive. In the 2010 base case the benefits of carbon sequestration are estimated at 13 million euro per year and the value of timber harvesting at 2.9 million euro per year. Under the examined policy scenarios aiming to reduce nitrogen emissions the societal benefits resulting from these two ecosystem services in Telemark are found to be reduced; the scenarios have little effect on terrestrial biodiversity. Such results cannot be scaled up, individual ecosystem services respond differently to changes in air pollution depending upon type of pollutant, type of ecosystem, type of service, and the magnitude of change. The paper further presents an analysis of the uncertainties that need to be considered in linking air pollution and ecosystem services including those in deposition rates, ecosystem responses, human responses and in the values of ecosystem services. Our conceptual approach is also useful for larger scale analysis of air pollution effects on ecosystem services, for example at national or potentially European scale.

1. Introduction

In recent years, there has been an increasing consideration of ecosystem services in environmental policy making (e.g. Daily et al., 2009; Maes et al., 2012). Ecosystem services have been defined as the contributions of ecosystems to human well-being and include such diverse aspects as products obtained from ecosystems (including crops from agricultural land), the regulation of biological processes (e.g. pollination, climate regulation) and non-material services including tourism and recreation (e.g. TEEB, 2010; UN et al., 2014). Ecosystem services can be expressed in both physical and monetary units and allow considering the effects of changes in the environment in cost-benefit analysis (Daily et al., 2009).

Until recently, the general approach in providing policy advice on the effects of reduced air pollution is to compare actual or future deposition levels with critical loads (see e.g. EEA, 2015). Critical loads are defined as the highest load that will not cause chemical changes leading to long-term harmful effects on most sensitive ecosystems (Nilsson, 1988; Hettelingh et al., 2007). However this damage based approach does not convey any information on the societal benefits of reducing air pollution loading (De Smet et al., 2007).

Hence, increasingly, ecosystem services are connected with air pollution. For example, the European Environment Agency analyses air pollution effects on ecosystems (EEA, 2015) and provides an estimate of the effects of ozone (O_3) deposition on timber

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production. Smart et al. (2011) applied an ecosystem services approach to analyse the benefits from air pollution control in the UK at the local scale. Jones et al. (2014) present a national scale analysis of the impacts of air pollution on ecosystem services in the UK, including the impacts of air pollution on wheat production and biodiversity. These studies show the importance of considering the multiple services provided by ecosystems as well as the spatial variation in deposition and ecosystem responses. Both vary strongly across the landscape and so do changes in ecosystem services supply as a function of reductions or increases in deposition (e.g. Jones et al., 2014). Although the number of studies in this field is growing there are still few that systematically link air pollution to multiple ecosystem services in a spatially explicit manner.

The objective of this paper is to examine how ecosystem services can be assessed in support of air quality policy formulation, using eutrophication in Telemark, Norway as a case study. We propose a generic, spatially explicit approach, and apply it to analyse the effects of atmospheric nitrogen deposition on carbon sequestration, timber production and biodiversity conservation. The approach combines an impact pathway approach to analysing impacts of air pollution (e.g. Dominici et al., 2010; Thompson et al., 2014) with an ecosystem services approach to assess impacts of air pollution (Smart et al., 2011) – in a spatially explicit manner. In addition, we analyse the methodological challenges and uncertainties in linking air pollution and ecosystem services.

We select Telemark in view of the sensitivity of European boreal forests and alpine ecosystems to eutrophication (Bobbink et al., 1998; De Vries et al., 2014) and in view of the large amount of data that are available on ecosystem services supply in Telemark, both from the detailed statistics of Statistics Norway, and from various papers (Schröter et al., 2014). We focus on nitrogen because boreal forests tend to react strongly to nitrogen (De Vries et al., 2014). We conduct our study for a specific county of 15,300 km^2 because we want to test an approach involving high resolution spatial modelling. Our study focusses on the EU, but is of wider relevance given the occurrence of air pollution in other parts of the world.

2. Methodology

2.1. Including ecosystem services in air quality assessments

Commonly considered pollutants in the context of European air quality policy making are SO_x, NO_x, N_2O, NH_3, Particulate Matter (PM), O_3 and VOCs. These pollutants are emitted in different ways, from near-surface sources such as exhaust pipes of cars or pipes of household fireplaces to industrial smokestacks. The pollutants follow different atmospheric dispersion pathways according to the height of the source, chemical transformations in the atmosphere, and the pollutant deposition velocity. For example NH_3 from agriculture is generally deposited close to the emission source whereas PM, NO_x and SO_x emitted from tall stacks travel larger distances (Amann et al., 2011).

Analysing how these pollutants affect ecosystems and influence ecosystem services supply requires consideration of the causal chain linking emissions to ecosystem service impacts following an Impact Pathway Approach (e.g. EPA, 2011). As a first element, this requires a description of emissions followed by air pollution modelling to calculate air concentrations and deposition. There are two deposition mechanisms. Wet deposition accounts for the effect of rainfall depositing pollutants in the ecosystem. Dry deposition depends on both the physical transfer of material to the surface and on uptake at the surface. Dry deposition depends on the pollutant and on the properties of the surface and so varies with ecosystem type.

The subsequent ecosystem impacts depend upon the mix of pollutants the ecosystem is exposed to SO_x and NO_x are main contributors to the acidification of ecosystems, whereas NO_x and NH_3 contribute to eutrophication. Not all pollutants entering the ecosystem are available for plant uptake, depending upon leaching and absorption in the soil complex. The response of the ecosystem to the pollutant is likely to be complex and can be characterised by dose-response functions. Whereas these functions may be assumed to be linear for specific pollution concentrations, non-linear reponses will often occur across the range of exposure (Aber et al., 1998; Smith, 1990).

Ecosystem change is usually a function of the combined effect of different drivers, and can only be meaningfully captured with multiple indicators for the state of the ecosystem, such as species composition, crown cover and/or pH of the (ground) water. Critical loads are an important concept in the assessment of ecosystem effects of air pollution (Amann et al., 2011). Critical loads represent the occurrence of thresholds in soils at which a rapid decrease in pH can be expected (due to the occurrence of calcium and aluminium buffers). At the point in time pollutant exposure levels start exceeding critical loads rapid changes in species composition (e.g. shifts in plant communities) and ecosystem functioning may occur, with implications for biodiversity, the ecosystem's capacity to supply services as well as ecosystem resilience, i.e. responses of the ecosystem to future stressors.

Importantly, a change in ecosystem condition, for instance when a critical load is exceeded, does not necessarily directly affect the supply of ecosystem services. Rather, changes in ecosystem composition and/or ecosystem functioning may affect the capacity of the ecosystem to supply services. The capacity of an ecosystem to supply services is defined as ‘the ability of an ecosystem to generate a service under current ecosystem condition and uses, at the highest yield or use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem’ (Hein et al., 2016a,b). Capacity indicates the maximum sustainable use level of the ecosystem subject to there being a demand for the ecosystem services involved (Hein et al., 2016a,b). The supply of ecosystem services depends upon the use of the ecosystem by people. If there is a change in ecosystem capacity to supply a specific service, people may respond by increasing or reducing the amount of service used (for instance to bring use of the service in line with sustainable use levels) – or they may not respond and continue with the same use level. In case capacity is reduced due to for instance air pollution such that present use levels exceed the capacity, this will lead to ecosystem degradation (Villamagna et al., 2013).

Generally, three types of ecosystem services are distinguished, i.e. provisioning, regulating and cultural services (e.g. MA, 2005; TEEB, 2010; Haines-Young and Potschin, 2012). Changes in ecosystem condition will affect the capacity of the ecosystem to generate the three types of services in different ways. The capacity of ecosystems to supply provisioning services generally depends upon the stocks and the annual increment of the species involved. Changes in condition resulting from pollution may affect the stock as well as the annual increment. Regulating services depend on ecological processes that take place at specific temporal and spatial scales, and often these are subject to naturally occurring fluctuations in addition to human stressors such as air pollution. The capacity to generate regulating services may be affected by changes in these processes. Cultural services include the non-material benefits provided by ecosystems. Recreation and tourism are the two cultural services that are most commonly included in ecosystem assessments (TEEB, 2010) and the capacity to support them may be affected by pollution leading to changes in the attractiveness of the landscape.