1 Introduction

The presently reached population together with the achieved degree of industrialisation can be considered the single most important driver for the usage and exploitation of natural resources although in many industrialised countries the perception to be overpopulated does not prevail. Not only the extraction of natural resources like minerals and fuels but also the release of sometimes hazardous substances to the environment need to be mentioned in this context. Although in many parts of the world policy has adopted respective laws in order to cut these emissions down to certain levels, the contaminants (still) released pose a potential threat to living organisms, be it humans, animals, plants or microorganisms in the affected regions. Economy which in principle takes care of the proper allocation of scarce resources comprising mineral resources, food, money, human capital amongst many others often fails when such side effects are not reflected in the prices of the respective goods being traded and finally consumed. These side effects are referred to as *externalities* or *external effects* and may in principle be positive or negative. In such *incomplete markets*, the market mechanism leads to allocation failures due to the lack of inclusion of external effects in the prices expressed in monetary terms. From a cost-benefit perspective, it is, therefore, necessary to convert these external effects into monetary units, especially in order to help in the policy decision-making process setting effort-effectiveness balanced regulatory standards. This in turn is done with the purpose to ensure societies to maintain or even increase their level of welfare.

Over the last decade in a series of projects funded by the European Commission, a methodology has been developed that assesses damages from pressures on the environment, most notably contaminant emissions to air due to energy conversion techniques (European Commission, 1995, 1999a; Friedrich and Bickel, 2001a). In a bottom-up analysis, this so-called *Impact Pathway Approach* follows the way of contaminants from their releases over their reactions and distributions in the environment (termed *environmental fate*) to the exposure and finally impacts on human health and other receptors such as building materials and crops.

In a second step, these impacts are then valued in order to yield damages in monetary terms. The monetised negative external effects are termed *external costs*. This approach is especially recognized in the area of externality valuation at the EU level (Rossetti di Valdalbero, 2004). Beside other criticisms, however, it lacks impact assessment schemes that take contaminations of the terrestrial and aquatic environments into account. Effects that were missing include: acidification and eutrophication, toxic impacts on non-human organisms potentially even leading to changes in biodiversity, and impacts on human health due to ingestion of food and drinking water. Damages to human health always by far (i.e., more than 90 %) dominate the external costs due to air pollution in the analyses undertaken so far (e.g., Friedrich and Bickel, 2001b; Droste-Franke and Friedrich, 2003). Additionally, the indirect exposure through food appears to be the dominant route of exposure to persistent substances (e.g., Finley and Paustenbach, 1994; Price et al., 1996) about which there exists public concern (Lindberg, 1989; Kabata-Pendias and Pendias, 1992; Council of the European Union, 1996a, 1996b; United Nations - Economic Commission for Europe, 1998; Parliament and Council of the European Union, 2000; European Commission, 2003f, 2003g; Barbante et al., 2004; Rat von Sachverständigen für Umweltfragen, 2004). Therefore, the framework for estimating external costs shall be extended particularly with respect to impacts on human health due to ingestion of contaminants.

Given that the existing Impact Pathway Analysis constitutes an approach to assess external costs from inhalation exposure, the purpose of the present work is to identify, provide and apply a methodological framework for the estimation of external costs due to ingestion exposures that is consistent with that for inhalation exposures. This means that the approach to be developed needs to fulfil the following requirements:

- providing assistance with respect to the evaluation of contaminants released by energy conversion techniques ending up in environmental media such as soil, water and foodstuff,
- providing the possibility to evaluate point sources like facilities as well as area sources such as economies across the whole of Europe in a spatially-resolved way,
- allowing for the assessment of impacts on human health at present as well as in the long run for example with respect to sustainability questions, and
- in contrast to risk assessments, striving for representative estimates rather than introducing a fair amount of conservatism.

Chapter 2 gives an introduction into human health and risk assessments in general and to the Impact Pahtway Approach in particular. It concludes with the formulation of the specific aims and requirements in terms of the modelling approach.

A general survey on existing environmental impact assessment frameworks will be given in Chapter 3. The realm of hazardous substances is rather large. Different substance groups, however, have different requirements as to the formulation of their environmental fate and exposure assessment. As is reasoned in section 3.2, the aim of the present work in the first place is to develop a methodological framework for the assessment of impacts due to oral exposure. For the tool development and case study part of the present work, consequently, a prioritisation of substances is undertaken in order to show the application of the methodological development. Chapter 3 concludes that none of the reviewed approaches fulfils the formulated requirements for impacts due to ingestion exposures towards the prioritised substances. Consequently, the needs for model development with respect to including the impacts due to oral intake of substances into the Impact Pathway Approach are identified and formulated. These will be addressed in the following methodological Chapters: on the general outline which includes the aspects of atmospheric modelling and spatial differentation of the ground into zones (Chapter 4), the environmental fate modelling of the terrestrial and aquatic environment (Chapters 5 and 6, respectively), the exposure and impact assessment (Chapter 7), and monetary valuation (Chapter 8). Note that the description especially of the environmental fate and exposure assessment parts are rather complex and are, therefore, only generally given in these Chapters. A more thorough documentation of these components is provided in Appendix A.

In Chapter 9, the developed approach for the prioritised substances will be evaluated. This will be done by means of a general discussion of the assumptions made and decisions taken, a comparison with independent data, scenario analyses, and sensitivity analyses of the key parameters.

The application of the extended Impact Pathway Approach to case studies is then presented. Principally two types of scenarios will be looked at: one dealing with marginal emission situations and the other with releases from whole economies (in Chapter 10 and 11, respectively).

The work will close with a Chapter on conclusions including perspectives (Chapter 12).