# Material resource taxation

## an analysis for selected material resources

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# Executive Summary

*Rationale for resource taxation*

The United Nations Environment Programme (UNEP) estimates that global annual resource extraction will rise from approximately 60 billion tonnes in 2005 to 140 billion tonnes by 2050. Current resource prices, however, neither directly reflect geological scarcity nor external costs and, as a result, resources are not used efficiently. In the face of this, international policy forums and the EU, which is increasingly dependent on imports, are promoting the use of economic instruments to trigger innovation and substitution.

Although the concept of resource taxation is well established for the energy sector, there are a number of specific issues that prevent the direct application of the lessons learned in others. Nonetheless, tax on natural resources or primary materials could create incentives for a reduction in material use and contribute to a more sustainable use of material resources at national and international levels. Furthermore, taxation should prompt the desired effects of substitution with recycled or other less scarce materials as well as more efficient use. Yet the level of taxation on non-renewable resources, other than for energy generation, is currently very low in EU Member States.

This paper focuses on the potential implications of a tax on non-renewable resources and materials as an instrument to trigger resource efficiency and reduce demand without impairing economic activity and employment. The main questions are whether a tax on resources is an appropriate instrument to achieve the desired efficiencies and which levels in the value chain should be targeted to increase its effectiveness. The paper aims to contribute to the discussion of the *Roadmap to a Resource Efficient Europe* and to increase an understanding of some basic principles, relations and fundamental issues concerning material resource taxation. The analysis is limited to non-renewable mineral resources.

*Choosing a level of the value chain*

The effects of a tax on a specific material resource differ according to the phase of the value chain to which it is applied because of the different innovation options and material-demand strategies industrial actors can take. In particular, demand elasticity to price (and then to the tax), market power and innovation possibilities can vary at different phases of the value chain of a material. For a single non-renewable material resource, three stages of the chain at which a tax could be applied were considered:

i. extraction;

ii. input of the material at the first industrial use; and

iii. final consumption of products embodying the material.

The resources/materials studied in detail were iron and steel, copper and phosphorus.

A unilateral domestic *extraction tax* in a country/region that is net importer of resources, such as the EU in which there are limited mining activities, will directly affect international trade. The tax would put domestic producers at a cost disadvantage compared to their foreign counterparts leading to a reduction of domestic extraction, an increase in imports, and potentially, depending critically on demand elasticity to price, a total demand reduction. Increasing imports will imply 'mining leakage' to other countries – the net resource effect of that can be nil in terms of the extracted material, while the net environmental effect can possibly be negative if the technologies abroad are worse than domestic ones.

A border tax adjustment (BTA) on imported minerals would neutralise the effect of a tax on domestic producers but its global effect on demand would depend on the status of the taxing country/region in the world market, with the size of the effects dependent on the price elasticity of demand. The three materials/resources considered in the case studies, as well as more general evidence, indicate that for minerals the demand elasticity to price is relatively low – they are largely non-substitutable inputs in subsequent transformation phases. The extraction tax rate, therefore, would have to be very high to bring about a reduction in global extraction.

A *material input tax*, such as a fertilizer tax that already exists in some European countries addressing phosphorus, is imposed the first time a material from a non-renewable resource enters industrial use. These taxes do not discriminate between domestic and imported materials and therefore do not need a BTA. However, they should be complemented by a BTA on the material content of imported intermediate and final products, which could make implementation difficult. In order for such a tax to be easily implementable, the main requirement seems to be that the variety of products subject to taxation is not too great. This would be the case for phosphorus, as it is mainly used in fertilizers.

The possible effect on demand for the material – and then for the resource – largely depends on demand elasticity to price, the possibility of substituting the material with others or with recycled secondary materials, as well the possibility of material saving for a given product. These possibilities are more likely to exist in industrial processes for complex products than at metallurgical stages. The case studies, however, illustrate that elasticity of demand is, in general, not great, substitution can be constrained even at very high material prices and that techno-economic constraints emerge for substitution by recycled materials.

Substitution and recycling pose two other main issues:

i. a substitute, such as aluminium for copper, can be resource and energy intensive; and

ii. recycled material cannot be easily distinguished from the virgin material.

Even though *taxing the consumption* of products that include large amounts of a specific resource is possible, its application can be challenging and its effectiveness uncertain. Although implementation seems rather easy in principle, there can be significant problems in identifying the share of a specific material within a final product, making the taxation base uncertain. In the case of metals in complex final products, their share of production costs and final price can be low, as in the case of luxury cars, thus preventing consumers from feeling a tax designed to induce them to switch to other less intensive products. Furthermore, consumers can reallocate their spending to other goods that use non-taxed resources intensively. Taxation at this stage, therefore, might be better thought of as a tax based on the intensity of multiple resources/materials, possibly taking a life-cycle analysis (LCA) perspective. In the case of simpler products, such as, for example, dishwasher detergent that contains phosphorus, while the implementation of a tax might be administratively possible, the likely reduction in extraction and use would be limited.

*Other issues*

The case studies point to the potential of improvements in resource efficiency at different phases of the value chain, and while taxation may be a good trigger mechanism, there are implementation issues at whatever the level of the value chain it is introduced.

Additional issues to be considered are:

Although the weight/quantity of the material resource can be used as the taxation base, the tax could be made proportional to resource/environmental externalities produced domestically, and the BTA proportional to the embodied externalities from foreign extraction sites. With this tax base, if the environmental features of extraction technologies in Europe were better than in foreign countries, the BTA would be higher than the tax, effectively becoming a net tariff on imports based on environmental pressures. The result, however, could be an increase in mineral production in Europe.

To achieve a reaction from industrial users or consumers, tax rates need to be sufficiently high regardless of where in the value chain they are applied. The case studies show that resources/materials have rather low price elasticity of demand – material resource costs often only constitute a small part of the overall cost of an intermediate/final product and changes in the material input might involve considerable cost. They, therefore, suggest that taxation would have to be very high to achieve resource-efficiencies. As these high rates might cause considerable economic change, adaptation costs and opposition from stakeholders, the resulting resource and environmental net benefits should be carefully measured.

The possibility of substitution is central to the effectiveness of resource input and consumption taxes, but it can also be a major shortcoming of a scheme designed to address a single material resource. In fact, the effects of substitution caused by one-material taxation can be ambiguous because:

i. taxation of a single resource might just result in substitution rather than overall resource efficiency; and

ii. substitutes of the taxed material may have other environmental disadvantages, higher energy intensity or lower recyclability, for example.

Taxing clusters of materials could be a better approach, but that might shift the problem to the level of material clusters, such as plastics *versus* metals, instead of single materials, copper *versus* aluminium, for example.

A tax – especially a tax on a material input – could, instead of encouraging substitution, stimulate technological solutions aimed at saving the taxed material, for example downsizing, which would be very favourable to resource efficiency. However, if material-saving innovations were not available or only at a non-mature stage of development, then their full deployment could only be justified by a high tax. Furthermore, given the complexity of material-intensive manufacturing products, such as cars or consumer electronics, it is likely that material saving innovation would require overall product redesign, which can have unpredictable effects on the material mix. Finally, downsizing and miniaturisation are often the outcome of broad technological developments, for example nanomaterials, on which the influence of a tax on conventional materials is difficult to detect.

Improvements in recycling are central to resource efficiency and the introduction of a circular economy. Taxation schemes based on input or consumption taxes should be designed so that only virgin materials, and not their recycled equivalents, are taxed. This can pose challenges in designing taxes for metals as the recycling rates of many, including steel and copper, are already quite high. A further increase in recycling can involve marginal cost increases that can only be covered if the tax rate on virgin materials is high enough. The case study on phosphorus, for example, shows that a sufficiently high price increase in phosphate rock or fertilizers creates incentives not only to reduce phosphate losses but also to recycle more, either in traditional ways such as the use of manure, or the introduction of modern technologies to, for example, extract phosphorus from sewage sludge.

Even under trade-neutral taxation schemes based on tax + BTA, it is not easy to envisage a unilateral European-level or country-level tax on a single material resource: such a unilateral tax raises the risk of cross-material substitution effects with uncertain resource and environmental implications. A global multilateral extraction tax on all non-renewable and non-energy resources, however, could be considered. Its expected effect is simply a world price increase of all resources, leading to global demand reductions. Even leaving aside the issue of political difficulties, the design of such a resource tax would be far from simple. Furthermore, price elasticity of demand (to the prices of all resources) will be relevant for the effect on global resource demand.

# 1 Introduction

## 1.1 *Policy background*

Natural resources form the basis of all human activities. Their use is increasing in the European Union (EU), which is highly dependent on imports for most resources (EC, 2014a; 2010), as well as globally (UNEP, 2012; EEA, 2010), but this is not sustainable in the long term. Since the possibility of the EU to increase supply from its own sources are limited, strategies to reduce resource use and import dependency have to be found, through substitution, more recycling or increased efficiency. The issue has been taken up in a range of strategies and initiatives in the EU, which set the framework for a European resource policy. These include the Europe 2020 strategy, the Raw Materials Initiative, the Thematic Strategy on the prevention and recycling of waste, as well as other EU and national initiatives.

The use of economic instruments as one tool for increasing resource efficiency and for moving towards a green economy is being promoted in international policy forums and by the EU. In its *Roadmap to a Resource Efficient Europe,* for example, the European Commission states that "*our economic system still encourages the inefficient use of resources by pricing some below true costs*" and considers "*getting the prices right and reorienting the burden of taxation*" as one of the means of achieving higher resource efficiency (EC, 2011). In addition to these policy documents there are a number of academic works that suggest that resource taxation can have significant effects on material saving (Barker *et al.*, 2011; Baumol, 2010; Ekins *et al*., 2009).

In spite of this, the level of taxation on non-renewable resources, other than in the energy sector, is currently very low in EU Member States and the divergence between, on the one hand, policy and academic prescriptions and, on the other, reality deserves a specific analysis.

## 1.2 *Rationale for resource taxation*

Global resource extraction, approximately 60 billion tonnes in 2005, is likely to rise strongly to around 140 billion tonnes a year by 2050 (UNEP, 2011a). The availability of resources is, however, limited, and, from extraction, through processing and use to disposal, the entire life-cycle has considerable environmental impacts. Current resource prices, however, neither directly reflect geological scarcity nor external costs and, as a result, resources are not being used efficiently. The principle of sustainability, which requires leaving sufficient resources to future generations, would require a slowing of extraction but currently this is not considered.

The reduction of dependency on natural resources and the primary materials derived from them is an important economic issue for resource-poor countries. Taxes can be used to provide price signals which encourage increased efficiency and could thus contribute to a reduction of import dependency.

Furthermore, to encourage employment and economic growth, a restructuring of the tax system, shifting the tax burden away from labour towards the consumption of resources, is often considered[1]. This tax shift from rather abundant human resources to scarce natural resources could deliver a win-win situation for the global economy.

[1] See ETC/SCP (2012) for a detailed discussion of these reasons for resource taxation.

Not all resources seem suitable for taxation. Materials that might be considered for a deeper analysis should fulfil at least one of the rationales for resource taxation[2]:

(i) a high and critical dependency on the respective material that is or could become problematic for an economy. This concerns materials with high economic importance or increasing demand and critical high import dependency, geological scarcity or geopolitical risk of supply[3];

(ii) the sustainability principle that leaves future generations sufficient resources is not currently considered; or

(iii) an environmental impact of extraction, use and recycling that is not reflected in current prices.

In these cases, a tax could create incentives for a reduction in a material's use and thereby contribute to its sustainable use on a national or international level. Furthermore, a tax should be able to trigger desired effects such as innovation, and substitution with recycled or other less scarce material.

Practicability plays a crucial role. For example, in case of significant trade, is the introduction of border tax adjustments (BTAs) necessary and possible? Further questions may also arise: are there practicable solutions for the taxation of semi-manufactured goods, i.e. can the tax base be determined accurately; are the necessary data available; are the taxes administratively manageable at a reasonable cost; and what effects will a tax have on welfare and economic activity?

## 1.3 *Specific issues of resource taxation*

This report assesses the use of resource taxation in the context of improving resource efficiency. It therefore differs fundamentally from studies that analyse resource taxation with a focus on fiscal issues and optimal taxation theory[4].

In this paper we distinguish between royalties and resource taxes, where the purpose of royalties is a fiscal one (rent extraction), while the purpose of a resource tax is on setting incentives for changes of behaviour towards less resource use. In practice, however, the effects of a royalty and a resource tax can, in some cases, be similar. The focus of this paper is on resource taxes and not on royalties.

The concept of resource taxation is well known from the taxation of energy resources. When it comes to non-energy resources, however, there are a large number of specific issues that prevent the direct application of the lessons learned from energy taxation.

With regard to external costs, for example, emissions are a good indicator for the environmental damage caused by the extraction and use of energy resources. While energy related emissions are global (greenhouse gases) or regional (nitrogen oxides, for example), externalities caused by the

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[2] For a detailed analysis of the rationale for resource taxation see e.g. ETC/SCP, 2012.

[3] Scarcity has not only a pure quantitative dimension with respect to geological reserves. Scarcity can also be also caused by other factors including market structure and environmental or social restrictions on their availability. For further discussion of "criticality", see ETC/SCP, 2012.

[4] For a conceptual overview of studies that analyse the effects of different fiscal regimes such as royalties, income taxes, production-sharing and resource-rent taxes on investors' exploration decisions, see Smith (2013). Empirical information on corporate income taxes, mining taxes and royalties in 22 mining countries is provided by PwC (2012). This report notes that, since the economic and financial crisis in 2008, many governments have raised taxes on mineral resources or are considering doing so.

extraction of non-energy resource arise mainly locally and depend to a high degree on the specific resource as well as site and method of extraction. Thus the determination of environmental damage is far less straightforward for non-energy resources.

Joint production is another difficulty. The composition of ores varies considerably between mines and some metals, such as indium or gallium, are secondary products; they occur in ores that are mined primary for other metals. In cases where the taxed resource is not the mass metal, which determines the profitability of a mine, the amount extracted is not likely to change much; instead, the taxed resource may be disposed of in tailings. In cases where the taxed resource is the mass metal, the supply of jointly extracted resources can be negatively affected.

A major difference between energy and non-energy resources is that energy resources are used up, while non-energy resources can be recycled if the product design allows. A high recycling rate is desirable and a taxation scheme should, therefore, promote recycling, or at least not impede it. The complexity of substitution of materials is another aspect that needs to be considered. Taxation may, for example, lead to the substitution of an easily recyclable material by another that is not, hindering the achievement of high recycling rates[5].

## 1.4 *Aim, scope, and structure*

This paper builds on the working paper *Resource taxation and resource efficiency along the value chain of mineral resources* (ETC/SCP, 2012), which demonstrated the complexity of resource taxation and showed that an optimal taxation scheme is likely to be different for different resources/materials. This paper provides a more detailed analysis of the potential use of resource taxation in Europe through case studies for selected resources/materials.

ETC/SCP (2012) analyses three possible taxation schemes on non-energy mineral resources:

"*i. a tax levied on resources at the point of extraction (extraction tax);*

*"ii. a tax levied on resources when they enter into production (material input tax);*

*"iii. a tax levied on resources embodied in a final product or on a resource intensive final product (consumption tax)"*.

The paper discussed the pros and cons of these taxation schemes and concluded, *"the taxation of resources other than fossil fuels is possible but much more complicated. The variety of different resources, recycling, international trade, co-production and the long production chains make the determination of the tax base, the implementation of a tax and the calculation of the effects difficult"* (ETC/SCP, 2012).

In this paper we further deepen the analysis of unilateral taxation, introduced by the EU or a single Member State, at three different levels of the value chain of mineral non-energy resources – extraction, manufacture of products and final consumption. The focus is on the possible outcomes and implications of the tax on resource and environmental efficiency, and not on the administrative feasibility or technical details of implementation of taxation schemes.

Appendix I illustrates the basic economics of resource taxation at any one of the three levels of the value chain – resource extraction, material input and final consumption – when the tax is adopted

[5] See ETC/SCP (2012) for a discussion on specific features of resource taxation.

unilaterally by an economy/region open to international trade that is a net importer of the material resource, as is the EU. The Appendix looks at expected changes of equilibrium in the market (domestic supply, import, total demand and price) when a tax – with or without a BTA – is introduced. It also illustrates the effects of the tax on material substitution and recycling and the possible market equilibrium outcomes of a global (multilateral) tax on resource extraction.

In general, an extraction tax is relatively easy to implement unilaterally from an administrative point of view, since the necessary data are available in most EU Member States. It influences the supply price of a resource and may therefore contribute to a reduction in extraction. Most resources used in the EU are, however, mined outside the EU, meaning that EU Member States have only limited options to apply this kind of taxation. To avoid competitive disadvantages for domestic extractive industries and/or leakage of extraction to countries with lower environmental standards, an extraction tax should be complemented by BTAs (Box 1). The combination of tax and BTA can induce a net decrease of resource demand (Appendix I).

The main purpose of a material input tax is to create incentives to increase resource efficiency at the production stage of goods. The determination of the tax base – target material input at first industrial use – seems to be simple, application problems do arise. To avoid ineffectiveness and trade discrimination, it is also necessary to take account of and to tax target material that is embodied in imported intermediate and final products, but it is extremely difficult to obtain the enormous amount of data that is needed to cover materials embodiment in products. As a consequence, while a BTA on the target material is not needed – the tax is on its first use whatever the origin – a more complex system of BTAs should be applied to all products embodying it.

A tax applied to final consumer products embodying the material can be expected to influence the behaviour of consumers, by, for example, substituting the taxed product with non-taxed ones or economising on its use, thereby prolonging the product's life. Its implementation might seem to be relatively easy, in particular as there is no need for BTAs, since both domestic and imported goods can be taxed at the point of final consumption. There are, however, two huge disadvantages. Firstly, as the determination of the single-resource content in final products can be highly complex, a consumption tax might be based on such proxies as 'high resource intensity' or 'use of critical materials', which would make it not targeted at specific scarcities or external costs and very open to lobbying and technical disagreements. Secondly, as the substitution of the taxed products by consumers is largely unpredictable and substitute products are hardly resource-free, the net resource effects are unpredictable.

As a tax is a price-based instrument, the sensitivity (elasticity) of demand to price is a critical element at all the three taxation options. In addition, given that most minerals/materials are primary commodities that have been extensively traded for centuries in well organised global markets, and the EU is a major actor of these markets, the international implications of any tax are should be considered (Appendix I).

**Box 1. Border Tax Adjustment (BTA)**

Taxes on national resource extraction or use can make the domestic industry less competitive. In a globalised world this may be an issue and can become a political barrier to their imposition. To avoid these negative impacts, a border tax adjustment (BTA) can be introduced. These usually encompass two elements:

i. a tax on import of resources or products embodying resources; and

ii. a refund to exported products containing the resource.

The import tax (or tariff) is to offset competitive disadvantages incurred by domestic manufactures that have to pay the resource tax. The export refund compensates domestic industries for the tax they have incurred, levelling the playing field in foreign markets.

The idea has already been discussed for climate policy measures but could also be applied to other environmental instruments. Border tax adjustment schemes have been suggested in connection with proposals for a European Carbon Tax, as well as to complement the EU Emissions Trading Scheme (EU ETS). In the latter proposals, the idea of a BTA based on carbon dioxide ($CO_2$) emissions embodied in imported products was to protect the working of the EU ETS from threats of carbon leakage and industry migration due to a loss of competitiveness because of the additional production costs associated with the EU ETS itself. The argument for BTA in climate policies was developed by Gros (2009) who suggests that to pursue global welfare, an import tariff based on the external impact of emissions would increase global welfare by equalising carbon pricing globally. Some other work, based on simulations with Computable General Equilibrium (CGE) models, suggests that a compensatory BTA in the EU could improve global welfare and produce the double dividend of reducing greenhouse gas emissions and improving global welfare (Majocchi and Missaglia, 2002). While convincing on theoretical grounds, and probably compatible with World Trade Organization (WTO) rules (UBA, 2009), the relationship between the EU and less developed producing countries, as well as questions of the security of supply, also need to be considered when designing a domestic tax and a BTA.

A contested issue of BTA is its measurement. If the domestic extraction tax is set in terms of resource units, per tonne of a mineral or its metal content, for example, the content of an embodied resource in imported raw materials, semi-finished, and final products needs to be measured, which raises problems similar to the estimation of $CO_2$ embodied in imported goods. If a domestic extraction tax is based on the externality cost of mining and energy extraction, the calculation of the corresponding BTA, based on externalities generated at the site of extraction, is much more complicated as externalities these can be site specific, material specific and time specific rather than global, as they are for $CO_2$. This difficulty could lead to an inefficient determination of the BTA, providing either insufficient protection to domestic extraction or discrimination in favour of domestic industry.

An extensive discussion of a BTA based on quantity rather than externalities applied in combination with a tax on mineral resources and industrial materials is presented in Appendix I.

Source: adapted from ETC/SCP, 2012

It is hoped that this paper will contribute to the discussion of the *Roadmap to a Resource Efficient Europe* and will help to raise understanding of some basic principles, relations and fundamental issues concerning material taxation. As in ETC/SCP (2012), the scope of the analysis is limited to non-renewable mineral resources, but excludes non-renewable fossil fuels, as well as other important fixed-amount resources such as water. A comparison of non-renewable mineral resource taxes with other policy instruments concerned with resource efficiency, including taxes on fossil fuels and waste, is not included[6].

The resources/materials analysed are iron and steel (Chapter 2), copper (Chapter 3) and phosphorus (Chapter 4) – all are essential in the economic value chain but have different characteristics and represent different groups of materials. For each, the analysis includes an overview of extraction, processing, consumption and environmental effects, together with consideration of the technical possibilities for improving resource efficiency, substitution and recycling. Based on the information

[6] We also exclude from the analysis the extraction tax on aggregates already applied in several EU Member States: while the materials considered here are mainly sourced from non-EU countries, and the supply chain and transportation are rather long, the extraction of aggregates is virtually in place in all Member States. There is limited international trade and short, economic transportation distances. Consequently, the experience with an aggregate tax not easily transferable to the materials considered here – or many other internationally traded minerals. A few additional comments on taxes on aggregates are presented in Section 5. On taxation of aggregates in Europe see EEA (2008).

on the three resources/materials and the economics of taxation (Appendix I), possible resource taxation schemes are analysed for each by exploring the likely consequences of taxation on industrial, environmental and particularly resource efficiency outcomes.

Chapter 5 provides an outlook on other materials, while Chapter 6 discusses the results and presents policy conclusions.

# 2 Iron and steel

Taxation on iron and steel might be considered for various reasons. Although there is no shortage of iron ore, the environmental impacts associated with its extraction and the production of steel are considerable. In addition, there is considerable potential to improve the efficiency of the final use of iron and steel products, while increasing the use of scrap as a substitute raw material still has potential.

## 2.1 *Industrial structure and international value chain analysis*

### 2.1.1 Iron ore reserves and resources

Iron (Fe) is a rather abundant metallic element since approximately 5 % of the Earth's crust weight is iron and indeed the average ore grade of the largest producer countries is high, about 65 %[7]. It is estimated that worldwide there are 800 billion tonnes of ore resources, containing more than 230 billion tonnes of iron. According to McKinsey estimates (2011a) known reserves, that is resources which could economically be extracted or produced in current conditions, are likely to last for about 75 years, while the United States Geological Survey (USGS) expect known reserves to last until around 2087 (Yellishetty *et al.*, 2010).

Iron ore is the raw material used to make pig iron, which is one of the main raw materials used to make steel. Approximately 98 % of extracted iron is used for steel production; therefore this paper considers both materials.

### 2.1.2 Extraction of iron ore

Global iron ore extraction has increased rapidly in the last 10 years following a relatively stagnant level of extraction of 1 000 million tonnes between 1973 and 2003. In 2010 (USGS, 2013c), the global extraction of iron ore was around 2 400 million tonnes, yielding a total of 1 320 million tonnes of iron – as well as other minerals contained in the ore.

Altogether, around 50 countries worldwide extract iron ore, of which 96 % is produced by 15 and almost 80 % in just four countries: China (27 %), Australia (20 %), Brazil (19 %) and India (12.5 %; USGS, 2013c),

The extracted amount, expressed as net weigh of iron, more than doubled between 2000 and 2010, from 607–1 320 million tonnes (mt) and is projected to triple, compared to 2000, by 2017.

**Import dependency of Europe**

Europe has to cover 80 % of its iron ore needs with imports from the major iron ore producers as Sweden, which has one of the world's largest underground iron ore mines located around the town of

[7] MEC Minerals Education Coalition http://www.mineralseducationcoalition.org/minerals/iron

Kiruna[8], is the only major producer of iron ore in the EU, accounting for about 1.2 % of global extraction in 2010, but 70 % of the EU's.

Table 2.1 provides an overview on changes in global and EU iron ore production, consumption and trade flows based on change from 2002 to 2010.

**Table 2.1**. **Iron ore production, consumption and trade flows, 2002–2010**

| | 2002 | 2010 | Change 2002-2010 (%) |
|---|---|---|---|
| Global production (million tonnes) | 1 100 | 2 590 | **135.5** |
| EU production (million tonnes) | 28 | 36 | **30.8** |
| EU share of world production | 2.5 % | 1.4 % | **-1.1** |
| Global consumption (million tonnes) | 1 088 | 2 526 | **132.2** |
| EU consumption (million tonnes) | 159 | 147 | **-7.7** |
| EU share of world consumption | 14.6 % | 5.8 % | **-8.8** |
| Total global import (million tonnes) | 513 | 1 020 | **98.8** |
| EU imports (million tonnes) | 136 | 120 | **-12.2** |
| EU imports of EU consumption | 85.6 % | 81.4 % | **-4.2** |
| Total global exports (million tonnes) | 525 | 1 083 | **106.3** |
| EU exports (million tonnes) | 5 | 9 | **90.0** |
| EU exports of EU production | 16.6 % | 24.1 % | **7.5** |
| EU self-sufficiency ratio | 17 % | 25 % | **7.2** |

Source: based on ECORYS, 2012

### 2.1.3 Processing and steel production

The vast majority, 98 %, of iron is used for steel production. However, crude steel production originates from two main sources: primary (crude) steel produced directly from iron ore and coke and secondary (crude) steel, produced from scrap steel. Of the total crude steel produced in the EU in 2000-2011, approximately 40–45 % was produced from scrap[9].

According to the EU's Joint Research Centre analysis of the energy efficiency of different European steelworks (JRC, 2012), a typical integrated steelmaking plant consists of a coke oven, a sinter plant, a blast furnace (BF) and either a basic oxygen furnace (BOF) or an open hearth furnace (OHF). The BF is fed with iron ore, coke and preheated air to produce pig iron (hot metal), which is then refined in a BOF or an OHF to obtain the crude steel.

Direct reduction (DR) of iron ore, an alternative method, is not a common in Europe but used more in developing countries where supplies of coking coal are limited.

[8] The majority of the world's iron ore mines are open pits (opencast mining).
[9] Copenhagen Resource Institute and Danish Technology Institute estimates based on Eurofer and Eurostat Data – in Sørensen *et al.* (2013).

About 58 % of EU crude steel production capacity is made up of BOFs, 41 % of electric arc furnaces (EAF) and 0.3% of the less efficient OHFs, which have largely been phased out in the EU (JRC, 2012).

Data from the International Steel Statistics Bureau[10] (ISSB) shows that the main European steel producers are Germany, France and Italy account for half of the EU total steel production of 200 mt annually for 2003–2008 – this dropped to 150–175 mt in 2009–2012.

Rates of scrap use as an input material vary widely across countries and depend on the technology used in steel production. While EAF production can use 100 % recycled steels as an input, BF and BOF production can only 20–30 %.

### 2.1.4 **Consumption**

Steel is one of the most common materials used in the world – it is a major component of appliances, automobiles, buildings, infrastructure, machines, ships, tools, weapons, and more.

In *Mapping resource prices: the past and the future* (2012), ECORYS finds that the strong increase in iron ore extraction is driven by global consumption of steel which doubled in six years between 2002 and 2008, from 1 088 mt to 2 281 mt, stalled in 2009 as a result of the economic crisis, but grew strongly again in 2010.

Projections for global steel consumption show a continuing increase over the next decades, with the highest demand growth projected for China, followed by India and other emerging markets. According to ECORYS (2012), economic booms in these markets result in explosive steel consumption induced by urbanization and industrialization, while in European economies, which are already more developed in this sense, steel consumption is more or less stable. The absolute level of consumption in Europe has not changed significantly, but the growth of global consumption has reduced the share of European consumption from 14.6 % of the global consumption in 2002 to 5.8 % in 2010 (ECORYS, 2012).

### 2.1.5 **After use: waste and recycling**

As iron and steel scrap is inert waste, it has low direct environmental impacts in the waste phase. Iron and steel are among the few materials that, in principle, can be endlessly recycled, reducing the need for raw material extraction and much of the environmental pressure and energy use associated with iron ore processing and steel production. Furthermore, as steel production from scrap is cheaper and 50–75 % less energy intensive than production from pig iron, a proportion share is already recycled.

As indicated by UNEP (2011b), the definition of recycling rates found in literature is not always fully clear. The so-called end-of-life recycling rate refers to functional recycling and includes recycling as a pure metal and as an alloy. The global end-of-life recycling rate for ferrous metals is estimated to be between 70–90 %, with the highest rates for iron. Eurostat, for example, estimates that 73.7 million tonnes of ferrous metal waste, mainly iron and steel, were generated in the EU27 in 2010, of which 61.6 million tonnes of waste (83.5 %) were treated – mainly recycled. Eurofer (2012), however, estimate that 70-80 million tonnes were recycled annually in the period 2003-2011, but these figures include on-site recycling.

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[10] See http://www.issb.co.uk/index.html

Considering the EU's import dependency on iron ore, a regulatory environment promoting recycling, high energy costs and the high value of iron and steel scrap, recycling rates in EU are assumed to be higher than the global average and at least on a par with, for example, Japan and the US.

According to a recent report (ECORYS, DTI and CRI, 2013), Spain and Turkey produced nearly 90 % of their steel from recycled material, mainly from imports from EU countries, in 2008, while the share of secondary materials in production was 77 % in Italy and 45 % in Germany. Elsewhere, the use of secondary materials in steel production was 64 % in the USA but considerably lower in Brazil, China and India. The primary source of secondary steel is the automobile industry.

Apart from the automobile industry, the highest recycling rates are found for large iron and steel structures such as buildings, bridges, trains, ships, etc., with recycling rates from municipal waste being much lower. Rates vary across EU Member States, with Austria, Belgium, Germany, Netherlands and Sweden typically being more efficient and effective at waste recovery than the rest. Member States with high recycling rates, however, do not necessarily produce a high proportion of recycled steel due to a lack of EAFs in these countries.

## 2.2 *Environmental impacts and current policy framework*

### 2.2.1 Environmental impacts along the value chain

Iron ore itself does not impact the environment, but its mining and extraction processes use chemicals pose risks to ecosystems, pollute soil, groundwater and surface water. Further impacts include landscape alteration especially when using opencast mining as these can affect local drainage systems due to inadequate landscape management (ECORYS, 2012). Because of the high volume and complexity of its operations and the extensive use of energy and raw materials, the iron and steel industry, as other heavy industries, has the potential to have a significant impact on the environment and human health. The main pollutants and wastes generated by major production processes fall into three primary categories: air pollutants, waste water contaminants and solid wastes.

The energy consumption of the steel sector alone accounts for about 6 % of the global final energy consumption, and as such is a major contributor to greenhouse gas emissions – about the same share (Carbon Trust, 2011).

The JRC (2012) provides the following figures on energy intensity of primary steel production: for BOFs, energy intensity in the EU varies between 17 and 23 gigajoule (GJ) per tonne of crude steel produced with an average of 21 GJ per tonne. The exact value is influenced by and depends on the iron ore and coal quality, the steel grade and the material efficiency. Open hearth furnaces are more capital intensive and less productive, but most OFC capacity in the EU was replaced at the end of the last century by BOF technology. Secondary steel production does not require coke or sinter plants as recycled steel scrap is melted directly in an EAF, the energy intensity of which ranges from 9.1 to 12.5 GJ per tonne of steel (JRC, 2012).

The greatest environmental impacts are therefore associated with energy use and consequently greenhouse gas and other emissions to the air from every stage of the process.

### 2.2.2 Existing resource taxation schemes on iron ore

Beyond the usual mining royalties (ETC/SCP, 2012), export taxes and duties, there are few practical examples of per unit taxation of iron ore, beyond taxing the revenue from iron ore mining, from which to draw conclusions, and it is as yet too early to understand the ex-post impacts of the few examples that are currently in place, as they are all very recent. One should observe, however, that production did not diminish in any of the countries in which the tax was implemented in 2012, China introduced a per unit iron ore extraction tax in November 2011 of CNY 10–25 (EUR 1.3–3.3[11]) per tonne depending on the ore grade. Due to the fact, however, that the extraction tax made imports from Australia even more attractive and domestic extraction more costly, the government reduced the total tax burden on the industry at the end of 2012.

In 2012, two Brazilian states, Gerais and Para, introduced a similar regime, taxing extracted iron at approximately US$ 1.4 per tonne in Gerais and around US$ 3.8 per tonne in Para, but the latter was quickly lowered to US $1[12]. The taxes have been challenged as Brazil's constitution, which only allows the federal government to raise such a tax as "*the revenue was not aimed at covering costs incurred by the state[s] for the usage of its services"* (PwC, 2012).

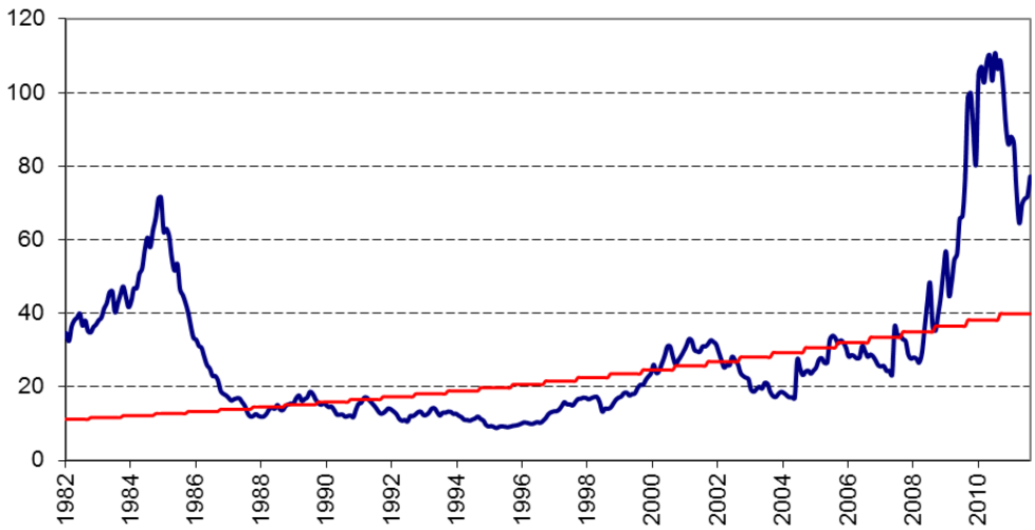
In July 2012, Australia introduced the Minerals Resource Rent Tax (MRRT), effectively a special tax on iron ore and coal mining levied by the federal government. This is not a per physical unit tax, but was intended to be a better, non-distorting tax on the income generated by the mining companies additional to royalties. After the federal elections in 2013, however, the new government repealed the MRRT from 1 October 2014.

## 2.3 *Possibilities to improve resource efficiency, substitution and recycling*

### 2.3.1 Price developments and its influence on demand - price elasticity

Figure 2.1 shows iron ore prices calculated at 2011 price levels. Historic data illustrates that real prices were relatively stable for 1988–2008, but then increased and became more volatile due to increased demand from China, India and other developing countries. The price of iron and steel scrap follows the price developments of iron ore (ECORYS, 2012).

**Figure 2.1**. **Monthly price of iron ore 1982–2011 (2011 constant Euros per tonne, best-fit linear trend in red)**




[11] As of December 2014, CNY 1 = EUR 0.13
[12] KPMG, Quarterly Commodity Insights, March 2013

Source: ECORYS, 2012

There are various, somewhat controversial forecasts of future iron ore prices. Apart from the ECORYS study (2012), various regular updates are available, including from the Economic Intelligence Unit and quarterly forecast updates from the World Bank. The literature, however, provides no consensus regarding future price developments. For example, ECORYS (2012) estimated that in a business-as-usual scenario (socio-economic drivers and conditions continuing along current trends) iron ore prices will increase from a 2011 level of about EUR 114 per tonne to around EUR 175 per tonne in 2020, an increase of 53.1 % over the period expressed at 2011 constant prices. Similarly the Economic Intelligence Unit[13] expects the iron ore price to be around EUR 180 per tonne by 2017 and the price of steel to be EUR 600 per tonne. The World Bank, conversely, expects future real prices to decrease or remain stable – its latest estimate of commodities prices, it forecasts iron ore prices to gradually decrease from US $128 per tonne to US $120 in 2020 and US$ 114 in 2025 in real 2010 US$ (World Bank, 2014).

The ECORYS (2012) report has identified some key factors and trends likely to influence iron ore prices in the near future: an oligopoly of supply, the expected growth of supply and market developments in China, India and their iron markets.

In their recent paper, Pustov *et al.* (2013) argue that it is not necessary to accept the assumption predicting decreasing iron ore prices. Their paper argues that the assumptions behind these forecasts are unclear or obsolete and that they are not likely to reflect deposit depletion and the limited potential of increasing supply. There is, however, no scientific consensus on a transparent price model either. It is most probable that economic activity (Gross domestic product) and improvements in mining technology are the major factors behind price levels in the long run (Zhu, 2012).

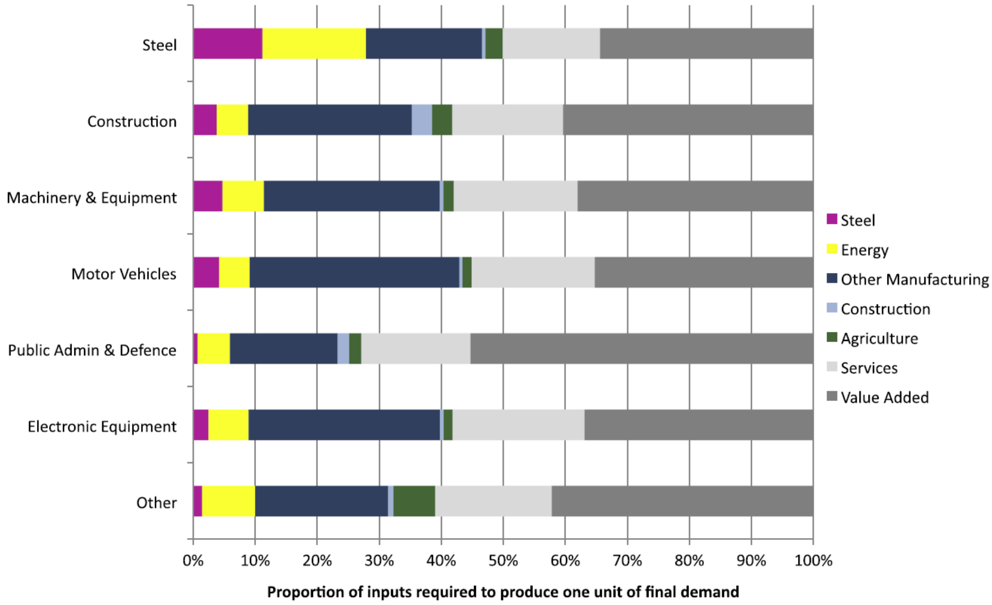
The global demand of iron ore is inelastic to changes in price, meaning that ore consumption is marginally dependent on its price, while for steel price elasticity of demand is in the range of -0.2 to -0.3 (Gonzales and Kaminski, 2011 referred in Pustov *et al.*, 2013). This can be both due to the oligopolistic nature of supply and the fact that the cost of iron ore is relatively low compared to the price of final products. Globally, the cost of iron ore makes up to around 30 % of the cost of rolled steel, which, in turn, contributes <5–20 % of the final cost of a product such as an automobile or building (Pustov *et al.*, 2013).

By using these data, one can calculate, therefore, that the cost of iron ore only makes up to 1.5-6 % of the price of the final product, for example, a car. This estimate is reflected in the results of Skelton and Allwood (2013) who used input-output analysis to map the composition of the total inputs required to produce one unit of final demand in steel intensive sectors. They found that in all the studied steel-intensive final products the actual cost of steel is below 5 % of total inputs and are outweighed by other manufacturing costs, energy use and value added including wages, capital depreciation and taxes (Figure 2.2).

Further reasons of inelasticity may include limited substitutability due to technological constraints and standards, for example, for structural material in buildings, or costs such as those involved in replacing steel in cars and other vehicles with composite materials or aluminium.

**Figure 2.2**. **The composition of total inputs required to produce one unit of final demand in steel intensive sectors**

[13] http://gfs.eiu.com




Source: Skelton and Allwood, 2013

### 2.3.2 Cost structure of the iron and steel industry

The cost structure of iron ore production is determined by various factors, including the type of iron ore, ore grade and transportation costs for example. Regarding the distribution of costs of iron ore producers, the main costs are related to contractors, secondary taxes and royalties, whereas fuel and energy account for 8 % and transport for another 11 % (ECORYS, 2012). According to ECORYS (2012), it is the degree of iron content in the ore and the transport distance has the largest influence on the costs, whereas these do not fluctuate strongly. Furthermore, the lower the ore grade is, the higher is the energy costs.

In the typical cost structure of steel production in Western Europe, the iron ore price makes up a more than 40 % of the steel production costs, hence if the iron ore price increases, it increases the steel price as well. As Europe is highly depending on iron ore from imports, the security of supply is becoming increasingly important in the face of rising iron ore prices and export duties or taxes levied by iron producers, such as India and China (ECORYS, 2012).

### 2.3.3 Technological and economic potential for improved resource efficiency: reduced use, recycling and substitution

A series of assessments published by the McKinsey Global Institute (2011a and 2011b) rank more than 150 options in terms of resource productivity increase potential and cost of improvement. They found that not only increased energy efficiency in steel production, but also improved end-use steel efficiency were among the top 15 potential opportunities for resource productivity benefits.

McKinsey found that the annual improvements in the steel sector had been around 2-4 % per year for 1960–1980 but had dropped to 0.5–1 % between 1980 and 2005. Looking forward, they estimated energy efficiency to increase by approximately 0.7% per year under baseline conditions.

Available technical improvements could increase the rate of annual energy efficiency gains to about 1.4 %, and McKinsey calculate that 40 % of the improvement opportunity is already available. Investment needs and returns, however, are major barriers for this improvement. Another great share of the potential could be achieved by changing BOFs to EAFs, with the main hurdle being access to cheap natural gas in Brazil and Europe, and the access to cheap coal in China.

With respect to the improvement potential of $CO_2$ intensity of steel production in Europe, the JRC (2012) shows similar data estimating that the $CO_2$ intensity will be reduced by 16 % between 2010 and 2030 in total, or 0.75 % a year, under business-as-usual conditions.

Skelton and Allwood (2013) used input-output analysis to estimate the potential to improve material efficiency along the steel supply chain and conclude that *"up to 94 % of metal in steel products can be lost along the supply chain due to yield losses"*. Stamping might be responsible for 32 % of metal losses and blanking for a further 10 %. As most of the loss is subject to on-site recycling, it does not contribute to net material losses, but causes excess use of energy, both in the production of waste parts and during the recycling process.

McKinsey (2011a) calculates, that another great potential of resource benefits could come from increased efficiency among the main final users of steel, who today account for 80 % of global demand: the construction sector that accounts for nearly half of global steel consumption, and the machinery and automotive sectors. They suggest *"there's an opportunity to reduce annual steel demand by 165 million tonnes in these sectors by 2030 by optimising designs and increasing use of high-strength steel (...) and out of this total, it is estimated that about 21 % is readily achievable"*.

McKinsey (2011a) highlights some iconic buildings, such as the Shanghai World Financial Center and Dubai's Emirates Tower, which have already used high strength steel. Furthermore, apart from saving on steel, this technology reduces the $CO_2$ emissions during construction by an estimated 30 % according to McKinsey (2011a). Similarly, the automotive sector has an estimated potential to reduce the weight of vehicles by a further 20–25 % through a combination of design optimisation and using high-strength steel. Even with currently proven technology, 35 million tonnes of regular steel could be saved in total by 2030 (McKinsey, 2011b).

Other studies also find high potential for improvements in product efficiency. For example Carruth *et al.* (2011) carried out a case study across five products with similar results: they found that through lightweight design 25–30 % of metal could be saved for construction beams, reinforcement bars, car bodies and crash structures, food cans and deep sea oil and gas pipelines.

**Recycling potential and limitations**

Recycling rates of iron and steel are already rather high, however, there is some technical potential to further increase rates in principle, partially due to better scrap collection and partially through technology innovation.

In a recent report Sørensen *et al.* (2013) identified factors limiting further improvements in recycling. It was found that some of these are hard – set by physics, chemistry, metallurgy and thermodynamics. The more complex a multi-material recyclate is, the more is lost in the metallurgical system. Mixed-metals waste often contains high levels of copper, which cannot be totally eliminated during the pre-treatment process. Especially over the longer term, this may result in the accumulation of copper in the steel recycling circle, eventually leading to too high a level of impurity for re-melting in furnaces.

Other identified limitations to recycling are related to the collection of waste, particularly post-consumer waste, raising question of waste collection systems and also social attitudes to and awareness of recycling (ECORYS, DTI and CRI, 2013).

In summary, the most important resource efficiency improvement potentials along the value chains of iron and steel – that could also be supported by policy instruments – include:

- reduction of environmental impacts of iron ore mining;
- general value chain optimisation and reduction of transport distances in processing;

- reduction of energy intensity of processing technology and switching to low-greenhouse gas energy sources;
- increasing recycling rates, substituting raw material with more scrap;
- reducing the weight of final products.

## 2.4 *Possible taxation schemes for iron and steel*

From the value chain analysis of iron and steel the following features emerge that are relevant to taxation:

- iron ore is not a scarce resource;
- the environmental impact is high at all stages of the iron and steel value chains;
- EU dependency on the international market for iron ore is huge, whereas the EU is still an important actor in world steel production;
- demand elasticity to price (ore and metal) is not high;
- the substitutability of steel in major applications is relatively low or very expensive – for example aluminium;
- there are significant but not radical possibilities of saving steel in major applications – for example construction;
- the present level of recycling is high but can be further increased at increasing marginal cost.

An **extraction tax** is here understood as a per unit (weight) tax on iron ore resources at the point of extraction that can be introduced unilaterally at a national or EU level. The theoretical idea behind such a tax – possibly complementing mining royalties – is to influence an increase in the cost of iron ore extraction and a reduction in the amount extracted. Immediate scarcity is not a strong rationale for the tax as, in general, high-grade iron ore is abundant. Rather, the environmental impacts of mining can be the rationale for taxation.

This tax would have little relevance to resource extraction within the EU, as most of the EU's demand for iron ore is met by extra-EU imports. Indeed, as Sweden is the only major producer in Europe, providing around 70 % of the EU's total extraction, the tax would only relevant to one EU Member State. The application of a tax on EU, or single EU Member States, domestic extraction would result in a competitive disadvantage for mining companies within Europe, and the Swedish ones in particular, extraction leakage outside the EU (Appendix I) and an in increase extra-EU imports. Therefore, a BTA on iron ore imports would be necessary to reduce the disadvantage of domestic extraction and avoid mining leakage.

A tax + BTA scheme is expected to reduce the EU's demand for iron ore, but, given that the elasticity of demand to price is not high, the net effect on demand might be limited. The EU is an important actor in world iron ore markets, and the demand reduction from the EU could be such that the world price would decrease thus encouraging EU imports and reducing the net effect on total demand (Appendix I). In short, given the high international openness of the EU and the low demand elasticity to price, the net effect of an extraction tax + BTA could be a limited reduction of iron ore demand and then of resource extraction. Most of the effect is likely to be on the cost of iron ore for steel production, with a possible onward transmission to the price of European steel and steel-using products.

An **input tax** can be applied to materials that are used in the manufacturing system, from both domestic and foreign sources, at the first point of industrial use. In Europe, Denmark has the most developed experience with using such taxes on several non-metallic materials. It makes sense, however, to distinguish between a potential material input tax on either iron or steel, or both.

In the case of steel in whatever form as an input to, for example, the construction or automotive industries, the possible effects of an input tax depend on the elasticity of demand and available substitution possibilities, but total demand for steel could decrease and substitute materials benefit (Appendix I). The net global effect would also depend on the strength of the EU in the world steel market, while the net resource and environmental effects would depend on the resource impact of substitute materials.

In the case of iron, the pig iron and basic steel products could be seen as inputs to other industries including the steel producing industry. The determination of the tax could be based on the iron content of these products – a per tonne tax on iron used in producing steel sheets. The imports of these input materials to European industry might be either in the form of iron ore, or pig iron, or intermediate steel products. Therefore, these imported primary or intermediate products could be taxed at first use according to their iron content. Although a BTA is not necessary for an input tax at first use, when considering the material content of these traded intermediates of the steel industry, BTAs might be still necessary on products containing it, as is the case for the Danish material input tax.

The advantage of an input tax would be that Europe would have an incentive to use materials more efficiently where its import dependency is high and the implementation of such a tax would be possible in countries that do not mine iron ore. As demonstrated by the various studies mentioned above, there is room for material use efficiency gains, and a material input tax could potentially contribute to improving process innovation, technology change, for example encouraging the use of EAFs, and spur the reduction of the weight of products.

Nevertheless, the iron ore demand, as well the demand for intermediate iron and steel products, appears to be rather inelastic and the material substitution potential is limited. It is not obvious, therefore, that a material input tax would reduce material/demand – and resource extraction – whereas it is likely to increase the production cost of steel-using industries. Furthermore, given the relatively low demand elasticity, an effective tax rate would have to be rather high (Appendix I) which would hit the steel using sectors in Europe even more.

With technological improvements in scrap processing and in EAF production technology, a tax on input might provide incentives for increasing scrap use in the EU. The application of the input tax must, however, be very careful as it is hardly possible to distinguish inputs from virgin iron and recycled iron/steel, which have much lower impacts on the environment. The risk of taxing recycled materials should be avoided.

The **taxation of iron or steel in final consumption products** could also be based on the iron/steel content of products such as a car, although targeting iron/steel only can be problematic as final products can contain a wide range of materials that also have significant environmental impacts. Given that precise determination of iron content in, for example, a car can be difficult, the tax could be either inaccurate or discriminatory. Furthermore, to have an effect on consumer behaviour, the tax would have to be very high, given that the share of iron and steel in the price of complex consumer products is not so great, for it to be felt *via* a tangible change in the final price. Accordingly, multiple-material taxation should be considered.

It can be noted that, alongside the hypothesis of taxing iron and steel at whatever stage of the value chain, there are on-going EU initiatives to boost steel consumption in Europe, making the two strategies inconsistent.

# 3 Copper

## 3.1 *Value chain analysis*

### 3.1.1 Key trends in production and reserves

The global rate of copper extraction and consumption is steadily increasing – the average annual growth has been 4 % over the last century and 2.1 % in the last decade.

For 2000–2010, world mine production increased from 13 mt to 16 mt, and, according to USGS projections, it is expected to reach 21 mt in 2017 (USGS, 2013b). Four countries, Chile, China, Peru and the US, accounted for around 55 % of world mine production in 2010. The production of refined copper, including recycling, is expected to grow from 19 mt in 2010 to 23 mt in 2017, with four countries, Chile, China, Japan and the US supplying 55 % of world production in 2010 – the year in which China surpassed Chile as the main refined copper producer with 24 % of total world production.

Total EU copper mine production was just 767,000 tonnes in 2010, of which 481,000 tonnes came from Poland – in the same year, the EU produced around 2.6 mt of refined copper. The EU copper industry is likely to remain stable over the next few years: domestic mine production is expected to increase by 0.7 % and copper refining by 8 % for 2010–2017[14]. These trends can be compared to global ones for both mining and refining, which are expected to increase by 31 % and 21 % respectively over the same period.

According to the USGS[15], the world's identified copper resources in 2013 were 2 100 mt to which 3 500 mt of undiscovered, i.e. postulated to exist, must be added. Of these, those that could be economically extracted in current conditions were 470 mt in 2005 and 690 mt in 2013 (USGS, 2013a), with 49 % of these reserves located in Chile, Peru and the US. The estimated depletion time in 2005 was 32 years of consumption, not substantially different from estimates of 38 years of consumption in 1950 when known reserves were estimated at 91 mt (Tilton and Lagos, 2007).

There is, however, no consensus on the question of copper scarcity. According to Tilton and Lagos (2007), the long-term trend is not one of scarcity and copper reserves could increase by the end of the century, while very recent estimates by Monash University's researchers suggest that the reserves could even cover up to 100 years consumption. On the other hand, Gordon *et al.* (2007) are critical of the results by Tilton and Lagos and conclude that the world is likely to experience a growing scarcity of copper.

### 3.1.2 The industrial and environmental value chain

Figure 3.1 presents the mining/industrial chain up to the semi-finished production stage of copper, including its relationship with the environment.

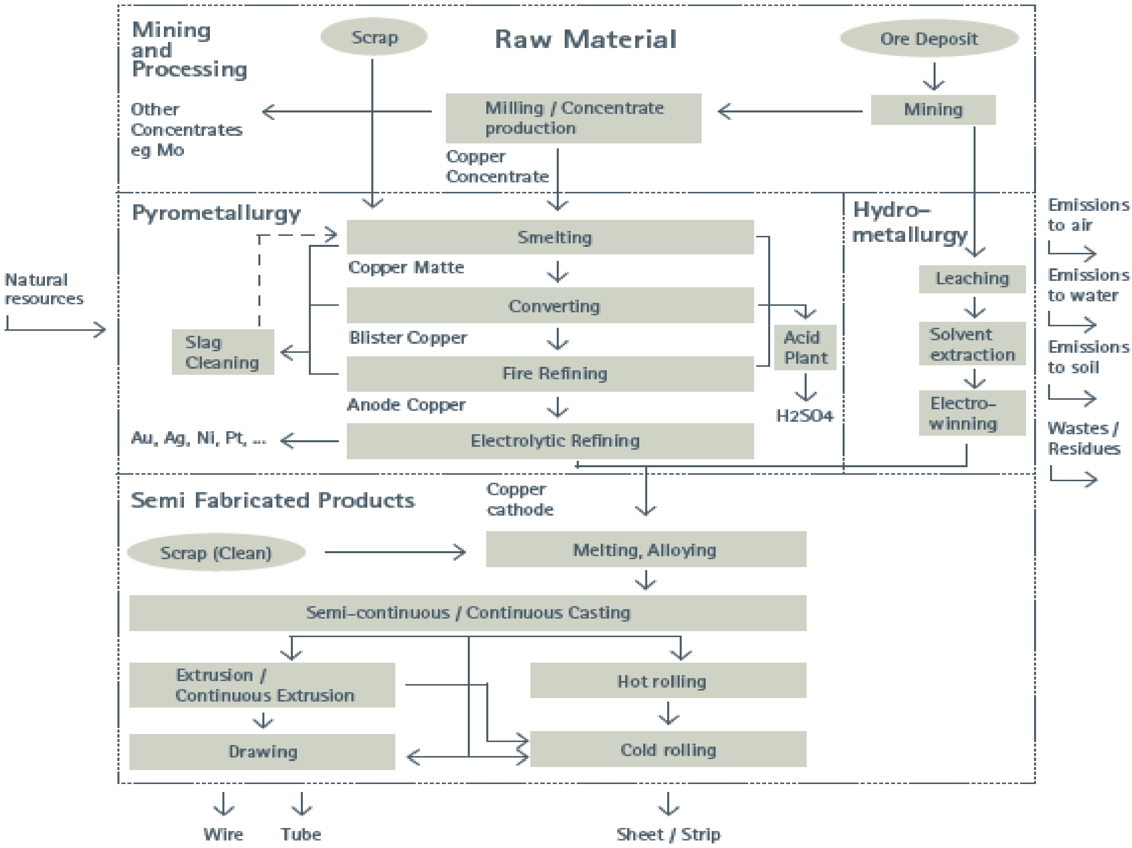
After mineral extraction, milling and concentration processes produce copper concentrate that is delivered to the pyro-metallurgical phase. This technology can also use scrap. In the hydro-

[14] Based on data from USGS (2010).
[15] See http://pubs.usgs.gov/fs/2014/3004/pdf/fs2014-3004.pdf

metallurgical phase minerals are delivered for leaching, solvent extraction and electrowinning[16]. Both technologies produce refined cathodes of copper, the pyro-metallurgical technology through matte, blister and anodes.

In the semi-manufacturing phase, cathodes together with clean (new) scrap are melted and cast to produce wires and tubes through extrusion, and copper sheets through rolling.

**Figure 3.1. The copper industrial cycle**




Source: European Copper Institute, 2012

Taking a material-flow perspective, the copper cycle can be divided into four phases:

1. production: mining/milling of copper ores and smelting of concentrates and scrap and finally the refining of cathode copper, which is 99.99 % copper;

2. fabrication and manufacturing: production of copper, and alloy, wires, tubes and strips from cathode copper or new scrap – production waste;

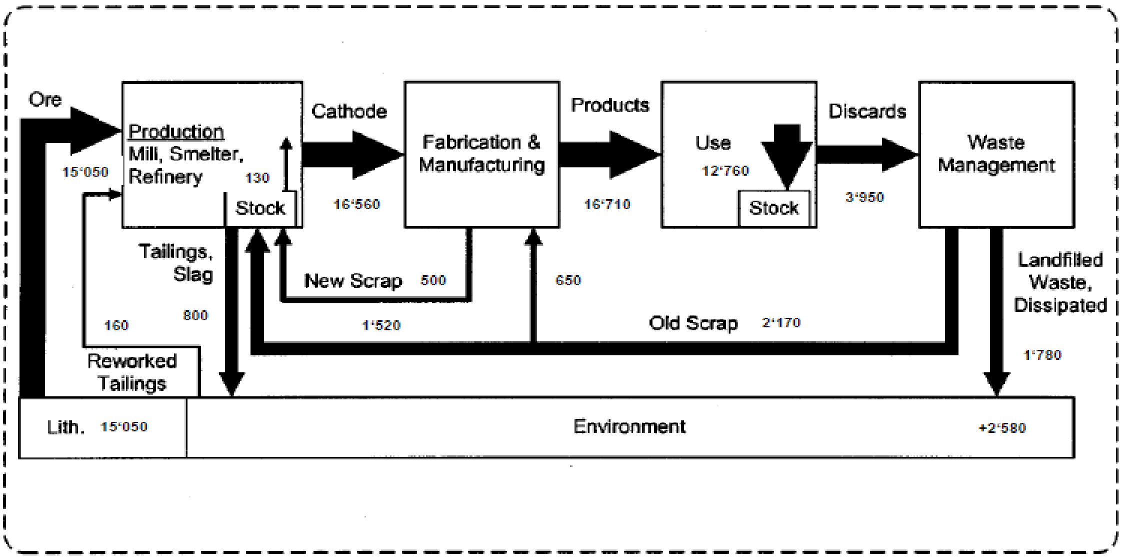
[16] In electro winning, a current is passed from an inert anode through a liquid *leach* solution containing the metal so that the metal is extracted as it is deposited in an electroplating process onto the cathode.

3. use: consumption of copper and alloy products in different applications and building up new stock-in-use;

4. waste management: collection and separation of copper scrap (old scrap) for recycling and final disposal in incineration or landfills (copper losses).

The global and European material flows of copper in the mid-2000s were calculated by Eugster (2008). At the global level, including Europe, (Figure 3.2), copper smelting and refinery received 15.05 mt from copper mining together with 0.5 mt of new scarp, residual from processing, from fabrication and manufacturing and 1.52 mt of old scarp from products in use. Smelting and refinery delivered 16.56 mt of cathodes to manufacturing, which also received 0.65 mt of old scrap as an input. Manufacturing of semi-finished products delivered 16.71 mt to final users, which accumulated stocks in use by 12.76 mt, and discarded 3.95 mt to waste management. Old copper scrap from waste management (2.17 mt) was delivered back to smelting and manufacturing while 1.78 mt of material was been sent to landfill and dissipation. The environment also received an estimated 0.8 mt of tailings and slag from smelting, and thus received a total of 2.58 mt of material compared to 15.05 mt of ore extraction.

**Figure 3.2. The global copper cycle in 2005, ktonnes**



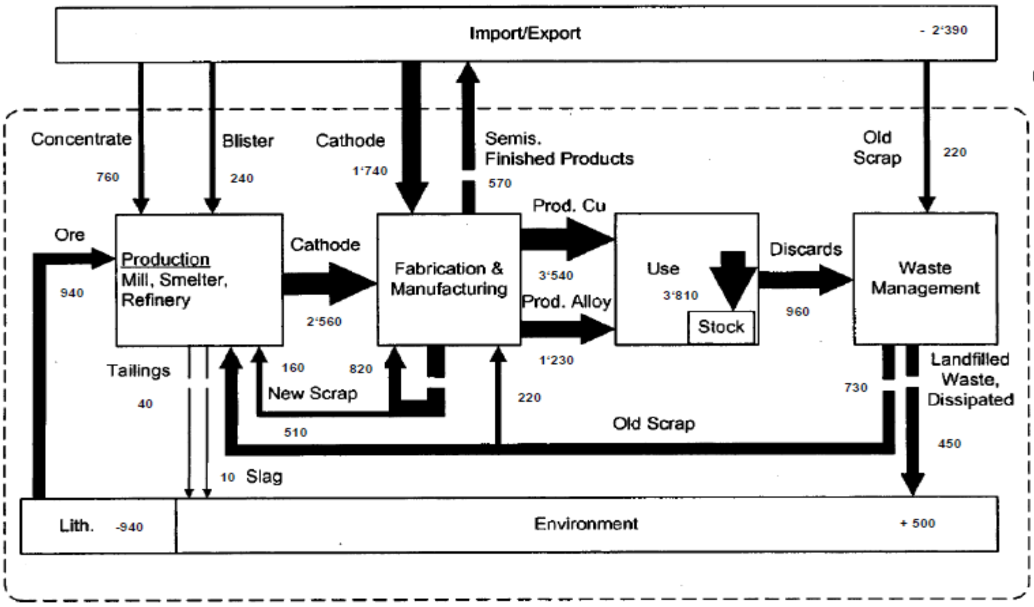

Source: Eugster, 2008

In the EU25[17] in 2005 (Figure 3.3), the domestic extraction of copper ore was 0.94 mt, which was augmented by the domestic smelting/refining industry with 0.76 mt of imported concentrate and 0.24 mt of blister[18]. Other inputs were 0.16 mt of new scrap (from manufacturing) and 0.51 mt of old scrap from waste management. The smelting and refining industry produced 2.56 mt of cathodes delivered to the manufacturing as semi-finished product. Manufacturing also imported 1.74 mt of cathodes and used 0.82 mt of new scrap together with 0.22 mt of old scrap. The manufacturing industry exported around 0.57 mt of semi-finished product. Manufacturing delivered 3.54 mt of copper products and 1.23 mt of copper in alloys for final use, with the final-use sector holding 3.81 mt in stock. The

[17] Romania, Bulgaria and Croatia are not taken into account as these countries joined the EU later.
[18] Blister is an almost pure form of copper that has a blister-like surface due to the release of gas during cooling.

discard from final use/stock was 0.96 mt delivered to waste management, which also imported 0.220 ktonnes of old scrap. Waste management delivered 0.73 mt upstream to refining and manufacturing and 0.45 mt to landfill and dissipation.

**Figure 3.3. The European copper cycle in 2005, ktonnes**




Source: Eugster, 2008

The following main features can be seen by comparing global and European figures:

- European domestic extraction is small, just 0.94 mt out of the global figure of 15.05 mt;
- European smelting and refinery production (2.56 mt) has a small share of global figure (16.56 mt), and the European industry is dependent on imports (concentrate and blister) for more than 50 % of its total inputs;
- the importance of imports (1.74 mt of cathodes) to European fabrication and manufacturing relative to domestically sourced inputs (2.56 mt);
- the great importance of old and new scrap as an input in Europe (1.71 mt, of which 0.73 mt of domestic old scrap), together with an import of 0.22 mt of scrap, compared to the global figure (2.67 mt);
- Europe's dependency on waste and recycling of copper is also confirmed by a recovery/waste ratio of 76 % compared to a global ratio of 54 %, and the recycling of of 0.980 mt new scrap (of which 0.82 mt is within fabrication/manufacturing and 0.16 mt in refinery/smelting) compared to a global figure of 0.5 mt in refinery/smelting only;
- the high absolute amount of metal dissipated/disposed off in Europe, 0.45 mt, which suggests a potential for developing recycling further.

These features make clear that any taxation schemes for copper must take the implications on international trade as well as recycling into account.

Copper has an extremely wide range of applications – the major final uses of copper, as wire, tubes and sheets, are in electrical wires (60 %), roofing and plumbing (20 %) and industrial machinery (15 %), with the remaining 5 % being used in alloys. By industries, 54 % is used in the production of equipment, 32 % in the construction industry and 14 % in infrastructure.

The European Copper Institute quantified the life-cycle assessment (LCA) environmental impact of copper (cathode) produced in Europe in terms of global warming potential (GWP) and primary energy demand (PED). Taking the average European producer, the GWP under the control of the cathodes producing plant is 20 % for copper sheets, 25 % for copper tube and 14 % for copper wire. The upstream phases, before cathodes, are responsible for 63 % of the GWP impact of wire, which uses more virgin metal, 53 % for sheets and 46 % for tube that uses more scrap in the input mix.

According to Eugster (2008), who examined data for 29 copper smelters and refineries located in Europe in 2005 and data on the most important trading partner for refined or intermediate copper products, production in Europe has the lowest impact at all levels of the chain (emissions to air and to water, and resource use), with a total index of 2.20 compared 8.38 in Russia and Asia and 6.24 in Central and South America.

Eugster (2008) also evaluated the economic cost of pollution from copper production in different scenarios. The total external costs in Europe according to the Base Scenario 2005 were estimated to be EUR 148 million for the production of primary copper and EUR 208 million for the production of secondary copper. Including imported copper from three of Europe most important trading partners, the total external costs were estimated to be EUR 2.9–5.1 billion, which should be compared with the value of copper sales in Europe – EUR 15.8 billion in total, or EUR 2 963 per tonne, in 2005.

Eugster (2008) calculated that to internalize the external costs (air pollution) of the copper value chain, the average market price for copper should be 33 % higher. Technological innovation, particularly in Europe's trading partners, could substantially reduce the total external costs.

## 3.2 *Potential for resource efficiency, substitution or recycling*

### 3.2.1 Price developments and its influence on demand/substitution

As taxation is a price-related measure, the price trends of copper are very important when calculating the feasibility and the likely effects of taxation. Figure 3.4 shows the development of the refined copper price in current and constant US dollars from 1960 to 2014. In the 2000s, both indices rose strongly, with the nominal current price increasing 315 % between 2000 and 2010 and real prices increasing 244 %. The reasons are the same as for other commodities: strongly increasing demand from emerging economies, speculation and a demand for real assets in the face of financial markets' uncertainty.

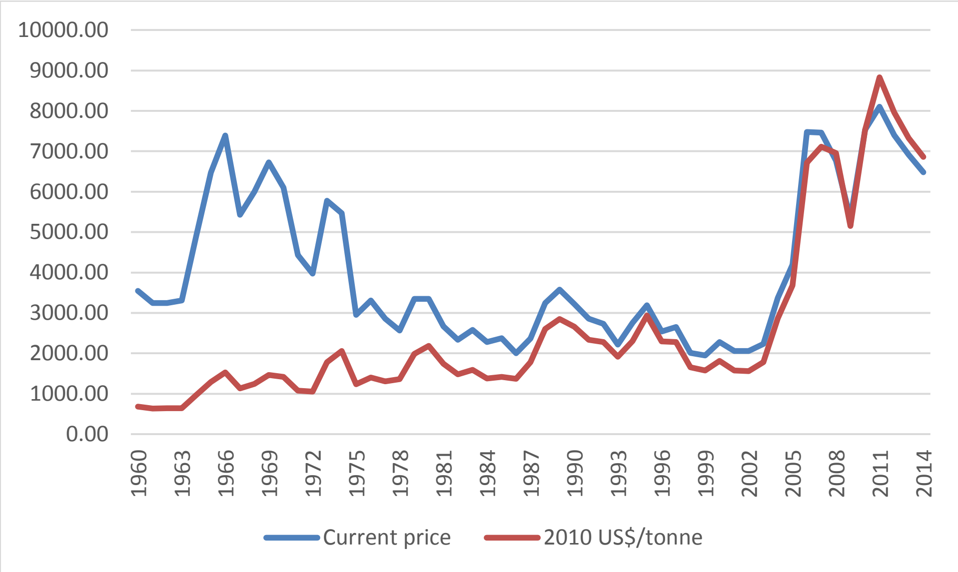
While demand for copper from industrial users (construction, electronics, etc.) decreased in Europe in the recession that started in 2008, - 23 % in demand from 2008 to 2009, it is still on an increasing trend at the global level. Recent market analyses report demand still growing faster than supply, which will continue the deficit of supply of 2011 and 2012. China and other emerging markets are driving the increase with Asia currently accounting for 55 % of global demand[19].

[19] http://www.asiaminer.com/magazine/current-news/from-the-editor/3335-copper-demand-outstrips-supply.html

While the possible role of high prices as a co-factor in decreasing demand in Europe is not fully understood, extremely high and increasing prices do not seem to affect demand at the global scale.

There could, however, be non-linear reactions to price. Commercial sources[20] suggest that copper prices of around US$ 10,000 per tonne are becoming unacceptable and that substitution is gathering pace in some uses, with aluminium and plastics major substitution beneficiaries in power and construction. Other applications possibly subject to substitution include plumbing tube, roofing and uses in refrigeration and air conditioning.

**Figure 3.4. International copper price, current and constant US$/tonne, 1960-2014**




Source: based on World Bank data.

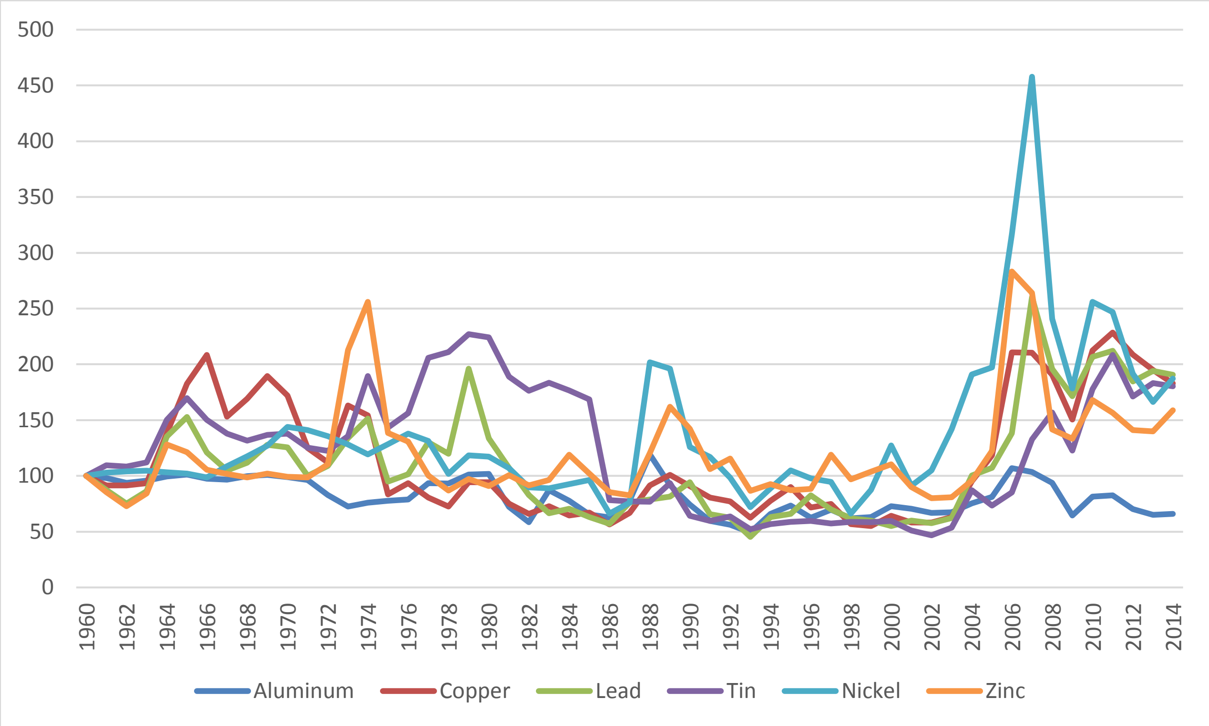
However, the exceptional surge in the copper price is common to all non-ferrous metals (Figure 3.5) with zinc and nickel prices booming even more than copper in the 2000s but with the exception of aluminium, the closer competitor of copper in important application. The possibility that copper suffers a process of substitution by other metals because of changing relative prices cannot be ruled out, especially in the case of aluminium. It is also likely that material saving processes involving copper as well as other metals/materials took place to some extent during the last few years.

Actually, according to International Copper Study Group[21], the market pressures from economic crisis severely encouraged the European copper industry to maximise their use of recycled materials. The European region (including Russia) recycled over 2.2 mt of copper, with a recycling input rate of 45.7%.

**Figure 3.5. Price indexes of major non-ferrous metals, 1960–2014 (index 1960=100; real 2010 US$)**

[20] http://www.commodities-now.com/news/metals-and-mining/5051-copper-substitution-gathering-pace.html

[21] http://copperalliance.org.uk/news-and-media/press-releases/percentage-of-copper-recycled-in-europe-continues-to-grow-239?year=2011




Source: based on World Bank data.

The possible effect of prices on demand and saving/substitution is better seen from model-based studies that cover a longer period (before the current phase) and look at structural factors.

When analysing the demand of copper, key issues that emerge from the examined literature are:

i. the homogeneity of (supply and demand) elasticities across metals;

ii. the difference between short- and long-term elasticities; and

iii. the statistical significance of both price and income elasticities in the demand function.

A recent paper by Lanz *et al*. (2011) presents supply and demand side elasticities within a study that is aimed at finding the eventual 'pollution haven effect' (i.e. production and pollution leakage towards less environmentally regulated countries) as driven by a US$ 50 carbon tax in advanced countries. The assessment of a 25 % leakage in emissions is based on the estimation of a set of supply and price elasticities by a dynamic econometric model that is able to unveil both short- and long-term elasticities. Those short- and long-term price elasticities for countries with a significant share of copper activities are low when looking at the demand side, more specifically in a range between -0.03 (lowest short-term value for Chile and Germany; top value is -0.09 for Russia) and -0.21 (again Russia peaks, lowest values in the long term is Chile, -0.06)[22].

Tcha and Takashina (2002) take an historical look at demand for main metals – steel, aluminium, copper, lead, nickel, tin and zinc. Subdividing by world region, they find that copper income elasticity is highly statistically significant and ranges between 0.576 (Latin America) and 0.903 (North America). As for most other metals, price elasticities for copper are not significant at all. In addition,

[22] Supply elasticities to price is variable by production (mines, smelters, refineries) and range between 0.11 (mines in Chile and Russia, short run) and 0.88–0.92 (US, smelters and refineries, long run).

they do not find any significant effect for the own price elasticities in the long run (1961–1993; accounting for three lagged years in prices), except for steel and aluminium.

The low level of demand elasticities is an issue raised also in a paper by Evans and Lewis (2005), who tackle the historical empirical evidence, *"a number of metals share a common demand curve which is stable over time"*[23]. They nevertheless find statistically significant price elasticities by using advanced econometric techniques at a dynamic level. Under different theoretical and empirical conditions – namely dynamic metals-demand models – they find that demand elasticities might vary across metals. They also suggest that each metal has its own short-term price elasticity of demand (aluminium, tin, copper, lead nickel, zinc and iron ore over the period 1969–1999). Statistically speaking, parameter homogeneity can be verified both for short- and long-term price/income – demand effects. Copper situates in a mean position regarding the level of price and income elasticities. The price elasticity in the short term is - 0.02, and lowers when estimating the lagged effect. In the long run, copper price elasticity is between -0.09 and -0.11, higher than the short-term value. Income elasticities are significant for copper, but not across all metals, and range between 0.77 and 0.79 (Evans and Lewis, 2005).

The result is clear: all tests reject the hypothesis that short- term and long-term elasticities with respect to income and price are homogeneous across metals. Metals are characterised by different reactions to price and income. In a previous paper, Evans and Lewis (2002) claimed that elasticities that were estimated in the literature could not be used to assess future rates of material substitution, given that metals do not share a common demand trend. They anticipated the more refined work presented in 2005 and concluded that:

i. demand coefficients are not stable over time as it was supposed ages ago;

ii. metals have similar but different rates of substitution when we test parameter's homogeneity; and

iii. it appears that copper and aluminium share a common price elasticity of demand.

Guzman *et al.* (2005) emphasise the role of price and technological development for the reduction of copper use intensity, which depends upon a balance between scale effects driven by income and technological effects driven by price and composition dynamics. Taking Japan during 1960–2000 as case study, they find that copper-saving technologies and other time related variables educed copper use by 2.9 % a year, more than compensating the scale/income effect, given that over the period copper intensity decreased by 39 % despite a GDP growth of 620 %[24]. The study suggests that the income effect itself is possibly turning into a negative relationship with copper use after the US$ 53,000 per person income threshold is crossed – this path determines a Kuznets inverted U shaped trajectory for metal use.

To sum up, main relevant works in the literature highlight that different metals present heterogeneous demands. Income and then production of intermediate and final products seem to have a greater impact than price, the effects of which are, as expected, larger in the long run but never very significant in terms of size. Copper price elasticity, when found statistically significant, is estimated as - 0.02 to -0.21 (-0.13 to -0.16 are alternative top range of values), when we take into account all empirical works.

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[23] For a common demand curve to exist between metals, all the metals placed on it must be equally good substitutes in each of their main end-use markets. It seems unlikely that metals are, generally speaking, good substitutes (see discussion in the text).

[24] The copper intensity changed as from 0.386 tonnes per 1995 US dollar in 1960 to a peak of 0.459 in 1973, before a decreasing pattern emerged leading to a 0.238 value in 2000 which was slightly higher than the lowest figure of 0.228 in 1998 (Guzman *et al.*, 2005).

These estimated values of demand elasticity suggest, similarly to market practitioners' perception, that only substantially high prices of copper can trigger substitution and saving, which implies that price-based measures (taxes) would have to be substantial to stimulate changes in copper use.

### 3.2.2 Technological and economic potential for improved resource efficiency, reduced use, recycling and substitution

According to Reuters[25], stimulated by increased prices for telecom cables (15 %), roofing strip (10 %) automotive heat exchangers (10 %) and plumbing tubes (5 %) in 2008/2009, there have been market losses for copper due to substitution by other metals and materials. Other major areas subject to substitution are air conditioning, electrical and electronic strips, and telecoms. Overall, the amount of copper substitution has been 130 000 tonnes in China, 80 000 tonnes in North America, 90 000 in Western Europe and 100 000 tonnes in the rest of the world.

According to EY (2013), which reports commercial news, copper demand has fallen by 400 000–500 000 tonnes annually in the last few years because of substitution, mostly by aluminium. The recent surge in relative prices of copper relative to aluminium stimulated a revival of this long-standing competition.

According to EY (2013), the main driver of aluminium substitution is the price differential. The copper/aluminium price ratio of 4:1 compared with an historical ratio of 2:1 or 3:1 at most, with overcapacity of aluminium production helping maintain its price advantage, can stimulate substitution. Major substitution threats to copper arise with a price of more than US$ 8 000 per tonne.

However, actual substitution is difficult to measure and in any case the switch to different materials depends on a complex set of micro-technical and economic factors that may require design adaptation, time and costs.

The cable producers highlight potential technical problems in switching from copper to aluminium, and the simple comparison of the price of the two metals can be misleading. Aluminium is lighter than copper, but its conductivity is lower – 61 % compared to copper. A more meaningful comparison is the cost per unit of conductance, which for aluminium is around half that of copper. The price of aluminium should, therefore, be divided by two for an accurate comparison in some applications, which would further favour aluminium. The layers surrounding the conductor, however, need to be more extensive in an aluminium cable than the copper equivalent, which partially offsets the cost saving. Similarly, in a power transformer, while aluminium strip is cheaper its copper equivalent, the transformer would need to be larger, requiring more use of other materials, such as steel.

Many electric utilities continue to prefer copper to aluminium, despite the lower cost of aluminium cables, but often the reason is established custom and practice – utilities are generally slow to change their technical preferences. Furthermore, experience with aluminium wires in the 1970s in the US highlighted serious problems, for example with fires, and therefore copper wires are required in most building codes.

In other applications copper substitution can be easier. An example is radiator material used in the auto industry in which aluminium is now preferred to copper. Similarly, there has been switching away from copper in some construction applications.

In other applications, technical performance can drive substitution, as in the case of optical fibres in telecommunications where substitution is driven by system performance and not material cost.

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[25] http://www.reuters.com/article/2010/12/23/us-factbox-substitution-idUSTRE6BM1N120101223

Nonetheless, more sophisticated electronics have enhanced the bandwidth that is available over copper pair cables, while DSL techniques have allowed improved performance using copper networks.

In short, substitution of copper is not so easy even with higher copper relative prices.

Recycling is an increasingly important source of copper, especially in Europe. The environmental advantages of recycling – secondary production – compared to primary production are well known. Although there are not reliable estimates of the copper stock in use, it is clearly increasing with the increasing consumption. However, as most copper applications have very long lifetimes, the annual amount of scrap available is approximately equal to consumption levels of 20–50 years ago. As a result, the demand for copper cannot be entirely met by recycling and requires significant quantities of primary metal. In short, a full and rapid substitution of primary for secondary copper cannot be envisaged, but recycling could be increased to save resources and environmental impacts.

An advantage of copper scrap is that, according to the US Bureau of Mines, the average copper ore grade (US) is steadily decreasing: in 1905 it was 3.6 % but in 1995 only 0.6 %. This means that more material must be extracted, increasing costs and environmental impacts. Data on the copper content in waste streams shows that, as post-disassembly concentrations lie above the metal's minimum profitable ore grades (Johnson *et al.*, 2007), recycling could be efficient in economic terms.

Rechberger and Graedel (2002) suggested that the current stock of copper in use has the potential to be a big future secondary reserve. However, only the high price of copper, possibly stimulated by decreasing concentration in ores, would justify recovery of a dispersed resource. While miniaturized technologies can cause large volumes of copper to be dissipated because of excess dispersion, the increasingly short life of consumer goods may add to the secondary reservoir and create scale effects in favour of recovery. Policies on waste, in particular for waste electrical and electronic equipment (WEEE) and end-of-life vehicles (ELVs), could make a difference in creating an organisational and economic framework for avoiding dispersion and an increase in recycling.

### 3.3 *Possible taxation schemes for copper*

Although there are taxation/royalty schemes in place in several copper producing countries aimed at raising revenues from mineral resource exploitation (PwC, 2012), there were no specific taxation schemes applied in the EU aimed at resource efficiency of copper mineral extraction and copper use as a metal until 2012, when Poland introduced a tax on the extraction of silver and copper. The tax rates in Poland are calculated per month on the basis of average market prices on stock exchanges in London and an average exchange rate of the US dollar and Polish zloty (PLN)[26] – the maximum tax rate for the extraction of copper is PLN16 000 (EUR 3 800) per tonne. This resource tax is too new to provide indications of its possible effects on resource efficiency.

From the value chain analysis for copper the following features relevant to taxation emerge:

- reserves of copper as a non-renewable resource is debated and uncertain;

- the environmental impact is high at all stages of the copper value chain;

[26] The details of the tax are described at http://www.finanse.mf.gov.pl/en/other-taxes/tax-on-extraction-of-certain-minerals;jsessionid=24DB488A42219005FE8605F11BCC55AC

- the EU's dependency on international copper market is huge at all levels of the production chain;

- the demand elasticity to price for ore and refined copper is very low;

- the substitutability of copper in important applications could be high, in particular from aluminium, but there can be technical barriers to substitution;

- there are limited possibilities of copper saving in major applications – for example, wire;

- the present level of recycling is high but can be raised further at increasing marginal cost.

A unilateral tax on **copper ores extraction** in the EU**,** a fixed amount per tonne, could be expected to have limited effects on the overall extraction demand. Copper mining in Europe produces very little compared to the amount of concentrates imported for smelting and of refined copper for the production of intermediate products such as wires, tubes and sheets. A unilateral tax on domestic extraction of copper ores, or on concentrate as an output, without a BTA, is likely to have adverse effects on the European mining industry and increase imports of ore/concentrates (mining leakage) to be used in metallurgical refining. Although we do not have full information on the environmental standard of the mining/concentrate industry compared to other countries, European standards are likely to be environmentally better, though mining areas in Europe could improve their environmental conditions by decreasing production, but at the expense of the local economy. However, increasing European imports can be expected to have adverse environmental impacts at the global level, although these effects would be largely country- and region-specific[27].

A BTA equivalent to the tax (per tonne) should be raised on imported minerals to avoid import substitution and international mining leakage. However, as the demand elasticity of copper ore to price is very low, the net effect of an extraction tax + BTA on EU total demand is likely to be limited and a mineral price effect, to be felt in downstream stages of the value chain (refining and semi-manufacturing), is likely to prevail. The overall demand reduction would be low as the EU is not a major actor in world import of copper ores and thus the 'large country effect', which weakens the demand-reducing effect of a BTA, is unlikely to take place (Appendix I).

The application a **material input tax** can be at the gate of the first user, with no differentiation made between domestic and imported material, and no BTA is needed. The level of application, however, can affect demand and prices. If the input tax were applied at the metallurgical phase, given that intermediate metallurgical products (from ore to refined copper) are the main input for each subsequent phase (input of ores in production of concentrates, input of concentrates in copper refining and input of refined copper in semi-finished products), the demand elasticity to price would technically be extremely low or nil.

A tax applied at one of the stages would lead to an increase in the production cost and thus of intermediate products, but have very low effects on demand – it would be equivalent to an output tax that affects the price of semi-finished products (tubes, wires and sheets). Therefore, an input tax at one metallurgical stage would not work too differently from an extraction tax: if the taxing country is open to the international trade in semi-finished products, a unilateral tax alone would imply a reduction of domestic supply, an increase of imports and a decrease of total demand – depending on demand elasticity to price – and a BTA on semi-finished products would be needed to avoid very high imports and metallurgical leakage. If the country/region were a large player in world markets,

[27] This conclusion also applies to iron ore and phosphorous.

decreasing demand would depress the world price, which would likely be reflected in a lower net decrease – or even an increase – in demand in the taxing country/region (Appendix I).

Conversely, an input tax on semi-finished products – the copper content of tubes, wires and sheets – in industrial applications such as car making can work differently (Appendix I). The tax on input – whatever the origin, domestic or imported – is likely to reduce demand, with a reduction of both imports and domestic production. If the country is a significant actor in world markets, this demand reduction could reduce the world price and thus increase demand even beyond pre-tax levels increase (Appendix I). Furthermore, a tax on the input of semi-finished copper products in manufacturing applications could face a more elastic demand than in mining and metallurgical phases because of potential copper-input saving technologies and substitution possibilities, in particular with aluminium.

However, three major problems could arise with an input tax on copper products.

Firstly, although an input tax does not require a BTA on the specific material as imports and domestic production are taxed in the same way, it would require a much more complex system of BTAs on all imported products that contain the material, and export refunds on all exported products. This can make the application of a system for detecting and tracking the copper content of all manufactured products, and identifying the non-domestically produced, and thus non-taxed, copper embodied in them, that is very demanding, particularly because of the very high number of products that contain copper.

Secondly, when looking at the possible effectiveness of taxation, the econometric evidence on the copper market suggests that demand for refined copper is inelastic to price, which would suggest the need for a very high tax to have saving/substitution effects. Similarly, as engineering and technical studies suggest that technical factors can prevent copper from being substituted for in many applications even if it is expensive, a very high rate of tax on copper would be needed to reduce demand.

Thirdly, where substitution can take place, the resource/environmental effects of an increasing demand for the substitute material, for example aluminium, may not necessarily bring overall net resource efficiency gains. This will happen whenever taxation addresses a single material for which there are substitutes. Therefore, copper input taxation, when administratively feasible, would only be favourable to resource efficiency if it stimulates material saving innovations and recycling.

Material saving innovation, with no substitution by other resource intensive metals, can face constraints in many copper applications but crucially depends on industrial users – for example, through product re-design in manufacturing and construction. An input tax can, however, directly stimulate this kind of innovation.

In the case of substitution through recycling – secondary copper from old scrap – two major issues arise. Firstly, as with other metals, secondary copper is difficult to distinguish from primary copper and this can create significant risks of taxing recycling if specific systems of material identification and tracking are not adopted. A possibility could be to tax just primary copper at first use, be it originated domestically or imported; however, if the tax is unilateral, this will exacerbate the identification of the virgin copper content of imported and domestically manufactured products (see above). Secondly, a large part of copper input in both smelting/refining and, partly, semi-finished production in Europe is both old copper scrap from (domestic) waste recycling and new scrap from metallurgy. As the rate of copper recycling in Europe is already high, and incremental recycling can have increasing marginal costs, the tax on virgin copper would have to be very high.

The following aspects, however, should be considered:

> i. the rate of copper production from scrap recycling is increasing, in part as a consequence of high virgin copper prices;
>
> ii. there is a significant absolute amount of un-recovered/dispersed copper in Europe;

iii. there are clear environmental advantages of recycling with respect to virgin copper production.

The increase of copper recycling could be a policy objective and it can be pursued by taxation/incentives. Just because the additional available sources of copper from scrap are more dispersed, the environmental burden of not recovering them is likely to be higher than that of more concentrated sources of scrap. This can justify a Pigouvian taxation/incentive scheme to support recycling – covering the higher costs of collecting and recovering/recycling of the dispersed metal. An interesting possibility is to combine taxation of virgin metal, with all its limitations, with using the tax revenues raised to subsidise recycling (secondary production). The expected outcome of such a scheme is described in Appendix I.

Indirect incentives to increase copper recycling are actually coming from waste policies, in particular in the areas of ELV and, very importantly for copper, WEEE policies. The producer responsibility principle enshrined in these policies, combined with legally binding targets for the recycling of the products can provide materials otherwise not available for recycling at relatively low cost – the cost is supported by producers of the goods and then possibly passed on to consumers – for example, the recycling contribution included in final price of consumer electronics in most national schemes for WEEE (Paleari, 2013). The inclusion of fiscal instruments to support copper or other metals recycling inside WEEE collection/recycling schemes could be envisaged as an additional way to implement producer responsibility. In this case, however, the tax would not be materials specific, due to material identification problems, but related to the product – this would be equivalent to the application of a tax on final products containing copper.

A **consumption tax**, a tax on the copper content of final consumer goods, would present some similarities with an input tax, but it would not require a BTA. Given the very wide range of uses of copper, taxing final complex products in terms of their copper content seems extremely difficult to implement due to technical information barriers, including from transit countries (Europe, non-Europe) of internationally traded products/inputs, which make a detailed account of embodied copper very challenging. There is a risk that such a tax would be inaccurate or, if applied to just copper, unduly discriminate between metals/materials embodied in the same product. However, if a measure of embodied copper were feasible, tax could be applied in the same way to the final price of both domestically produced and imported goods. In any case, to affect consumer behaviour by raising prices, the tax would have to be extremely high and, even then, it is unlikely to affect the consumer price of complex consumer products, such as luxury cars, in which copper is only a small fraction of its overall production cost.

# 4 Phosphorus

The need for action on phosphorus[28] is evidenced by:

i. there is no substitute for its main use as fertiliser;

ii. its environmental impact is considerable;

iii. reserves are very unequally distributed between countries which might become geopolitically challenging;

iv. during the last decades the need to use lower grade deposits has risen; and

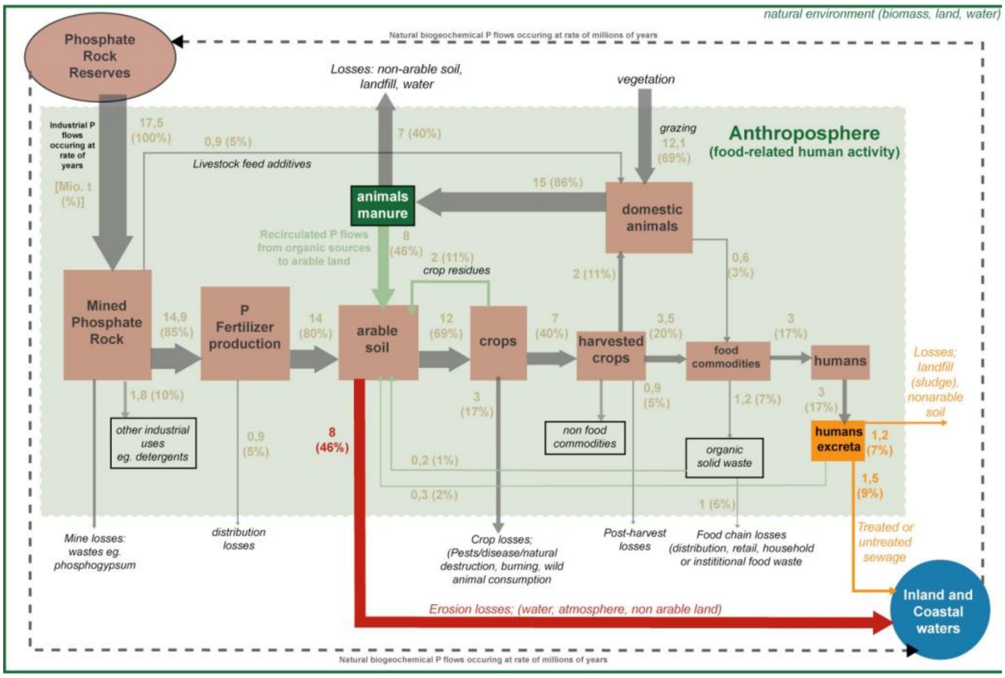
v. deposits with high impurities of heavy metals, especially cadmium, or uranium are less suitable for fertiliser production.

## *4.1 Industrial structure and value chain analysis*

### 4.1.1 The main uses of phosphorus

As about 85 % of extracted phosphorus (P) is used in agriculture (Figure 4.1), tax related to this use is likely to be most effective.

**Figure 4.1. Global phosphorus flow**




Source: Lange, 2009

[28] Phosphorus refers to the chemical element. The common chemical compounds in which phosphorus is extracted, traded and used are phosphates.

The figure shows that there are different starting points to influence the phosphorus cycle: by reducing inputs, closing material cycles and reducing losses to the environment. It has to be borne in mind, however, that as a certain amount of phosphate is needed in soil for agricultural production, from an environmental point of view, the use of phosphates as fertilisers needs to be optimized, not minimized. The goal should be, however, that there is no phosphorus surplus in agriculture. Compared to other resources, the overall picture of the phosphorus cycle is rather simple, and as a result, measures at some single points could significantly influence phosphorus use.

### 4.1.2 The value chain of phosphorus

**Reserves and Extraction**

The main source of phosphorus fertiliser is phosphate rock, which is concentrated in very few countries, with the International Fund for Cultural Diversity (IFCD, 2010) suggesting that Morocco controls 85 % of usable or marketable global reserves. European reserves are negligible and according to EC (2013) the EU's overall import dependency is 92 %, clearly demonstrating that the option of an extraction tax does not exist for Europe. Even though estimates of reserves and resources differ substantially, with some researchers even assuming " peak phosphorus", decreasing rates of phosphate extraction, in this century (UNEP, 2011c), it is clear that the availability of phosphate rock is limited. Because of the unequal distribution of resources and geopolitical issues that could affect supply in the near future, there is a need to use lower grade deposits and deposits with higher impurities of heavy metals.

**Consumption**

The main use of phosphate is as fertiliser with only about 15 % of production used in detergents, as a food additive and in other agricultural and industrial products. Currently China and India are the largest consumers of phosphate fertilisers and their consumption has steadily increased in the last decades. On the other hand the consumption in Europe plunged in the early 1990s and now is relatively stable. A further global increase of demand can be assumed because of an increasing demand for agriculture products triggered by population growth, an increase in meat-rich diets and the demand for bioenergy crops. There will also be future regional demand differences – the next years, the Food and Agricultural Organization of the United Nations (FAO) expects a slight global increase in demand of 1.9 % annually, and of 1.7 % in Europe but a slight decrease of 0.7 % a year in Western Europe (FAO, 2011)[29].

Fertiliser phosphorus consumption varies strongly between European countries, from 3 kg P/ha/year in Greece to 13 kg P/ha/year in Portugal, with an EU average of about 6 kg P/ha/year in 2010 (van Dijk *et al.*, 2013). Between 2000 and 2008 the phosphorus fertiliser consumption increased in a few countries including Hungary and Poland but decreased in many other countries (Eurostat, 2011).

It is not entirely clear how much the use of phosphorus for other purposes than fertiliser will and can change in future. It can be assumed, that the use of phosphorus as water softener in dish and laundry detergents will decrease as environmental impacts are enforcing regulations for further reduction of use and substitution. On the other hand higher demand for food together with the change towards higher processed food and a higher consumption of meat may lead to a higher use of phosphorus as food and feedstuff additive.

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[29] For details of development of fertiliser consumption in indifferent countries see http://data.worldbank.org/indicator/AG.CON.FERT.ZS. For a forecast of European Fertiliser consumption for single countries see Fertilisers Europe (2012).

**Processing**

Figure 4.1 shows that, compared to other industrial products, the phosphorus production chain is rather short. Furthermore, the production of fertiliser, mainly used in the form of superphosphate or triple superphosphate, from phosphate rock requires few chemical processes[30] and companies in many countries are able to process phosphates. Because the production chain is simple, the product is rather homogenous and the number of players is rather small, administrative efforts for the implementation of a tax are manageable. In case of incomplete competition it is not entirely clear who has to bear the tax burden and price effects have to be scrutinised.

## 4.2 Policy experiences

Over the last years the awareness of the necessity to deal with the "phosphorus problem" has grown. In 2013, for example, the European Phosphorus Platform[31], directly connected to the European Innovation Partnerships on Raw Materials, Water and Sustainable Agriculture and the research and innovation agendas of Horizon 2020, was established. Its focus is, however, more on recycling options and not on economic instruments for setting incentives for a reduced use. The Global Phosphorus Research Initiative (GPRI) states in its *Blueprint for Global Phosphorus Security* (GPRI, 2012), "*appropriately designed policy tools such as market-based instruments are needed to increase the use of recovered phosphorus from mining and fertiliser processing*".

### 4.2.1 Examples in European countries

In 1991, the EU implemented the Nitrates Directive (91/676/EEC) to control pollution and improve water quality but this Directive also affects the use of phosphorus through its rules on, for example, buffer strips and maximum application limits for nitrogen in manure. In addition, many Member States include phosphorus measures in their nitrate action plans. Tax on materials containing phosphorus, *per se*, is rare although some European countries have introduced taxes on fertilisers which aim, *inter alia*, to reduce phosphorus use – in most cases the taxes were introduced for environmental and/or fiscal reasons.

**Finland**

In Finland, a tax on fertiliser was in place from 1976 and in 1990 a specific tax on phosphorus was introduced, which in 1992 was combined with a tax on nitrogen and also significantly increased. This tax increase coincided with a decrease in fertiliser use. However, most of this decrease can be attributed to a set-aside programme, since the fertiliser consumption per unit of utilized agricultural area hardly changed (Nienhaus and Knickel, 2004). Finland's accession to the EU in 1995 led to a major change in agricultural policy, including the introduction of an upper limit for nitrates in line with the EU Nitrates Directive that had much stronger effects on fertiliser consumption than the tax, which was repealed in 1994.

**The Netherlands**

For a few years, the Netherlands chose the use of economic incentives to comply with the EU Nitrates Directive. In 1998, they introduced the Mineral Accounting System (MINAS), which targeted nitrogen and phosphate surpluses rather than inputs. This focus has the advantage that only nitrogen

[30] For more detailed information on the chemical processes see UNIDO/IFDC 1998.
[31] http://www.phosphorusplatform.org/

and phosphate losses are taxed, not the necessary input. Farmers were obliged to declare the mineral surplus on their farm, which was based on the volume of nitrogen and phosphate that had been supplied to the farm in the form of fertiliser and feed, and disposed of in the form of products and manure. A tax had to be paid for excess emissions above a given levy-free surplus, which was reduced over the years and tax rates increased (Söderholm and Christiernsson, 2008). After a period during which it was only compulsory for large pig, poultry and dairy farms, the system became compulsory for all farms in 2001.

Although the system proved to be effective in decreasing total nutrient losses for some farm types, its overall results are mixed (Söderholm, 2009, Söderholm and Christiernsson, 2008 and Nienhaus and Knickel, 2004). In their evaluation of the programme, the Organisation of Economic Co-operation and Development (OECD) concluded that the regulation had strong effects on dairy farms, probably had some effects on arable farms but was ineffective for pig and poultry farms (OECD, 2004). Further drawbacks were the high administrative costs and the fact that MINAS was accompanied by other instruments that were not always very supportive. The system was finally abolished in 2006, as it failed to implement all elements of the EU Nitrates Directive.

**Denmark**

Denmark introduced a tax on mineral phosphorus in animal feed in 2005 as part of the plan for improving the aquatic environment (Larsen, 2011). While in previous years the focus was on the reduction of nitrate leaching, the Action Plan for the Aquatic Environment III (APAE III), which runs from 2004 to 2015, includes a stronger focus on surplus phosphorus in agriculture; its aim was to halve this by 2015, using the 2001/2002 surplus of 37 700 tonnes as the baseline. There was a midterm evaluation of the APAE III in 2008, which came to the conclusion that the implementation so far had not had the anticipated effects[32].

**Austria**

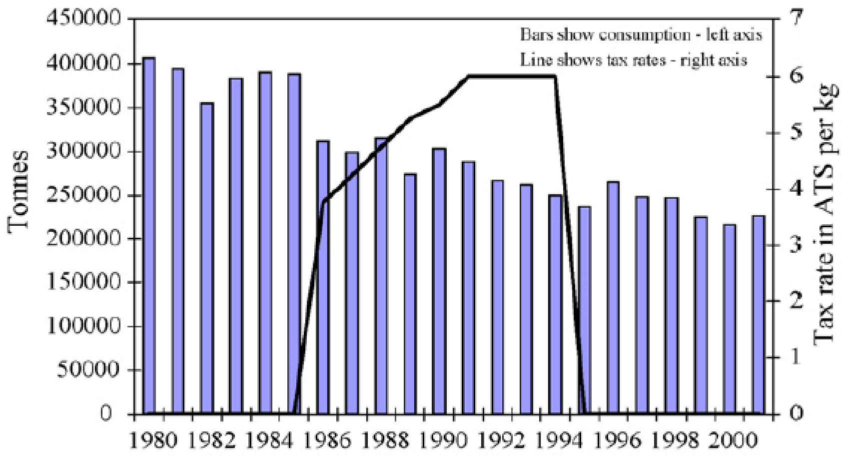
Austria's 1985 tax on fertilisers included a specific tax on phosphate amounting initially to ATS 2.0/kg/P (EUR 0.15) but increasing over the years until the tax was abolished in 1994 just before Austria joined the EU (Nienhaus and Knickel, 2004 and Söderholm and Christiernsson, 2008). Environmental aspects such as soil conservation were only secondary concerns, the tax's primary goal was to raise funds to support the grain production sector through export subsidies.

Analyses conclude that the long-term impacts of Austria's tax may have been more significant than the immediate ones, since farmers became aware of the impacts of fertiliser use on the environment and also of the fact that fertiliser consumption is a cost factor (Hofreither and Sinabell, 1998). The decrease in fertiliser consumption (Figure 4.2) may also to a large extent be explained by such factors as changes in production patterns and anticipation of higher future prices (ECOTEC, 2001, Bel *et al.*, 2002).

Söderholm and Christiernsson (2008) provide an overview on the competitiveness effects of the tax, pointing out the importance of a policy mix. While the impact on consumers of food products was insignificant, grain farmers and the fertiliser industry faced losses, which were, however, moderated by the fact that, in the case of grain farmers, tax revenues were used to subsidise grain exports and, in the case of the fertiliser industry, the prevailing agricultural import policy prevented import penetration.

[32] http://www.mst.dk/English/Agriculture/nitrates_directive/action_plan_aquatic_environment_3/

**Figure 4.2. Total annual fertiliser consumption and taxes in Austria, 1980–2001**




Source: EEA, 2003 and Sjöberg, 2004; in: Söderholm and Christiernsson, 2008
Total fertiliser consumption refers to the amount of nitrogen, phosphate and potash consumed.

**Norway**

Norway's tax on nitrogen and phosphate in fertilisers was in place from 1988 to 2000. Its introduction was triggered by the 1987 declaration of the states surrounding the North Sea, which aimed to reduce discharges of nitrogen and phosphorus by 50 % (Vatn *et al.*, 2002).

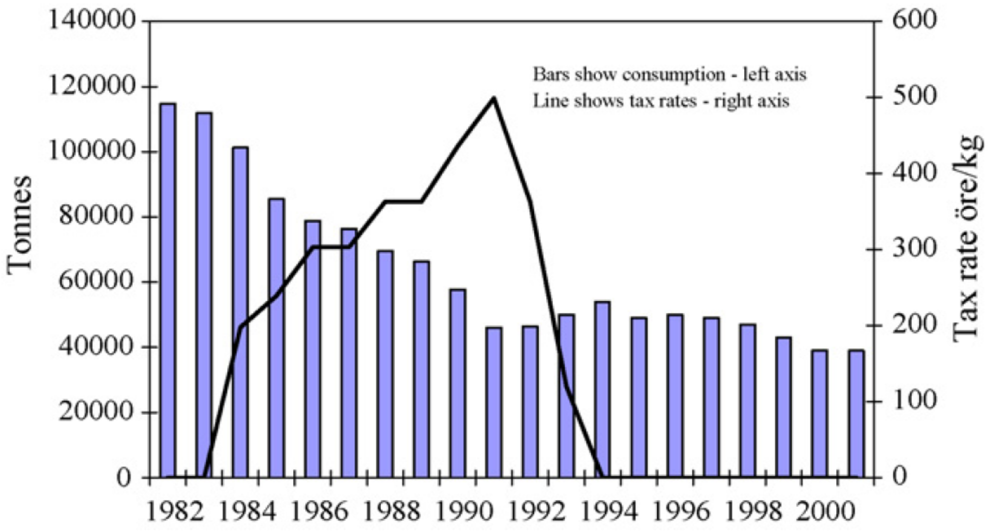
The tax was not very effective due to its low level – in fact the main purpose of the tax seems to have been fiscal (Söderholm and Christiernsson, 2008). However, it never led to an increase in the price of fertilisers, as the additional costs were absorbed by producers and importers, and, indeed, after its introduction in 1988 the use of chemical fertilisers even increased (Rørstad, 2004).

**Sweden**

Two instruments were introduced in Sweden in 1984 that have had an influence on phosphorus consumption: a fertiliser tax on nitrogen and phosphorus, and a so-called price regulation charge, the primary aim of which was to raise funds to finance of export subsidies – it was abolished in 1992. In 1994 the tax on phosphorus was also removed, as its reduction goal of 50 % had been met, but it was replaced by a charge on the cadmium content of commercial fertiliser (Lindhjem *et al.*, 2009, Söderholm and Christiernsson, 2008, Speck *et al.*, 2006 and Oosterhuis *et al.*, 2000). The relationship of this charge to phosphorus is in the fact that cadmium occurs at varying concentrations in mineral deposits in phosphate rock, so phosphate fertilisers are frequently the source of cadmium pollution in the soil.

The aim of the taxes was the reduction of demand for fertilisers and thus the leakage of nitrogen and phosphorus to the environment. The objective of the cadmium charge is to provide incentives to either use phosphate rock with less cadmium content or to purify the fertiliser. It is set at SEK 30 (€3.3) for every gram of cadmium that exceeds 5 g/t P (Söderholm and Christiernsson, 2008; ECOTEC, 2001). Taxes apply to all producers and importers of fertilisers; there are no exemptions.

**Figure 4.3. Annual phosphate ($P_2O_5$) fertiliser consumption and tax rates (including the price regulation charge) in Sweden, 1982–2001**




Source: EEA, 2003 and Sjöberg, 2004; in: Söderholm and Christiernsson, 2008

Figure 4.3 shows the development of fertiliser consumption and tax rates, including the price regulation charge. The consumption of phosphate decreased steadily between 1982 and 1992, when the price regulation charge was abolished, and demonstrates the stronger price effect of the higher price regulation charge compared to the fertiliser tax. The reduction of phosphate use after 1994 is partly attributable to the cadmium charge (Söderholm and Christiernsson, 2008). ECOTEC (2001) argues that while the tax on phosphate fertilisers did have an effect on the use of fertilisers and thus on discharge into water, the main effect was an indirect one brought about through the financing of action programmes to decrease its use.

With regard to competitive disadvantages that the tax imposed on Swedish farmers, Söderholm and Christiernsson (2008) conclude that effects are hard to isolate from other factors and while such negative effects exist they may not necessarily be significant. The authors cite government investigations, which came to the conclusion that despite of competitive disadvantages for Swedish agricultural products "the current taxes (and tax levels) should be retained as they are judged to be environmentally effective".

### 4.2.2 Environmental impacts and current policy framework

The need to reduce phosphate use is mainly fuelled by the high environmental impact of phosphates – their negative impact on inland and coastal water (eutrophication). So the first goal of phosphorus-related environmental policy was to substitute it where possible to reduce eutrophication. In Europe the use of sodium triphosphate in laundry detergents is no longer not very common and this has already improved the quality of water bodies. Substitution of sodium triphosphate in laundry detergents was based originally on voluntary actions but is now mandatory.

A further need for action is caused by the impurities of phosphate rock, especially heavy metals. In many countries quality standards already exist for phosphate fertiliser with regard to heavy metal concentration – for EU-countries see Oosterhuis *et al.* (2000), while Sweden has a tax on cadmium content. Additionally, radioactivity caused by phosphate rock containing radionuclides is of concern and in the US there is a maximum allowance for radioactivity from phosphogypsum used in agriculture.

Policies that influence phosphate use mainly concern the agricultural sector, which has the greatest possibility of influencing the phosphorus cycle as it use the most  and is the most important stakeholder. What makes any political action in this sector so difficult are the facts that the agricultural sector faces strong international competition, that it is seen as a relevant economic sector, that it receives strong political support and many subsidies in most countries, and that it has a very strong lobby.

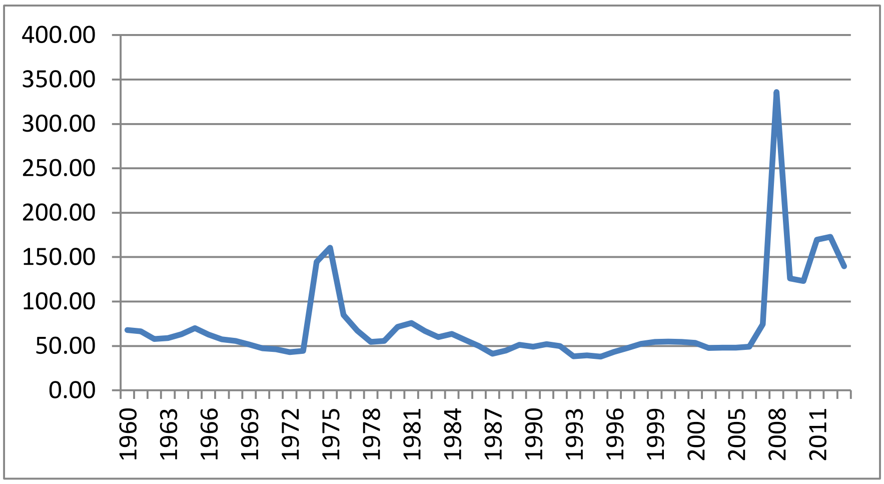
## *4.3 Potential for resource efficiency, substitution or recycling*

### 4.3.1 Price developments and their influence on demand

As taxes influence the behaviour of agents through the increase in prices, an analysis of price developments and the effects of price changes on production and consumption can provide an indication of the potential effects of a tax.

Figure 4.4 shows the development of phosphate rock prices since 1981. For more than two decades it remained stable and phosphate rock was a relatively low-cost bulk commodity, but in 2008 the price rose suddenly by 800 % and currently is still about four times higher than before 2006. Phosphate rock prices may be influenced by supply; export tariffs, a relevant example is China; transportation costs, especially from energy prices; direct demand, especially for fertiliser; demand of agricultural products; and, in the short-run, speculation on commodities markets. The recent general price trend has no clear single explanation, but one important reason is probably the growth of agriculture production, including animal breeding, and thus the demand for fertiliser. Furthermore after two decades of rather stable prices and the slowly declining phosphate content in phosphate rock, a price increase was not surprising. Thus, the 2008 price hike was likely to have had several different causes, such as increased demand for phosphate-based fertilisers in India and China, high energy prices (Gilbert, 2009) and the introduction of a high export tariff in China. Looking forward to 2025, however, the World Bank now expects prices to sink slowly to about US$ 100 per tonne[33].

**Figure 4.4**. **Price of Phosphate rock 1960-2013 (real 2010 USD)**




Source: based on World Bank Data.

[33] http://siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1304428586133/Price_Forecast_May13.pdf

Phosphate rock consumption fluctuates slightly every year but in general is slowly rising. It is difficult to detect a general relationship between prices and demand – overall demand of fertiliser depends not only on its price, but also on such other direct and indirect factors as the phosphate content of soils and thus the need to fertilize them; the demand and price of agriculture products, where the demand for meat and population growth play an important role; agricultural subsidies; the development of biofuel policies; and energy prices. This implies that economic growth and changing patterns of consumption and diets play an important role. However, it can be observed that the price of fertilisers do influence demand although according to Oosterhuis *et al.* (2000) there is limited information available on the price elasticity of phosphate fertilisers – the only example they cite is Sweden, where the short-run price elasticity is assessed to be in the range of -0.1 to -0.25. Also Pearce and Koundouri (2003) conclude that the experience of fertiliser taxes shows that price elasticity is rather low and therefore taxes must by very high compared to the price to reach quantity reductions.

Shakhramanyan *et al.* (2012) model a potential tax on phosphorus for the US that internalizes environmental externalities – they calculate an average external cost of US$ 8.29 per kg $P_2O_5$ – but central to their model is the assumption that it will be possible to substitute mineral phosphorus with organic fertiliser. The results suggest that more than a 10-fold price increase of the year 2000 reference price would be required to reduce mineral phosphorus input by 50 %.

Thus, it seems to be difficult to estimate the effects of higher prices on direct fertiliser use. There are indications that fertiliser prices would have to change substantially to effect a significant change of use. Higher prices might trigger the implementation of further resource efficiency measures, and, as the introduction of fertiliser regulations has shown, there is potential to reduce phosphate use but market prices currently do not provide enough of an incentive to use all available measures.

For products other than fertiliser, the cost of phosphates is less importance. A rough calculation shows that for dish detergents, for example, about 30 % of which are phosphates, the price for the phosphate content is not more than a few per cent of the retail price[34]. Thus, to have any effect, a tax would have to be extremely high compared to the price of phosphorus.

#### 4.3.2 Technological and economic potential for improved resource efficiency, reduced use, recycling and substitution

Figure 4.5 gives a rough overview how inefficiently phosphorus is currently used in agriculture. It shows that in the end about 90 % of phosphate rock input is lost.

[34] Assuming a price of EUR 4/kg for dish detergents and a price of US$ 150/tonne for phosphate rock (70 % phosphate content), and an exchange rate of US$ 1.35: EUR 1.

**Figure 4.5**. **Simplified Cycle of phosphorus in agriculture**

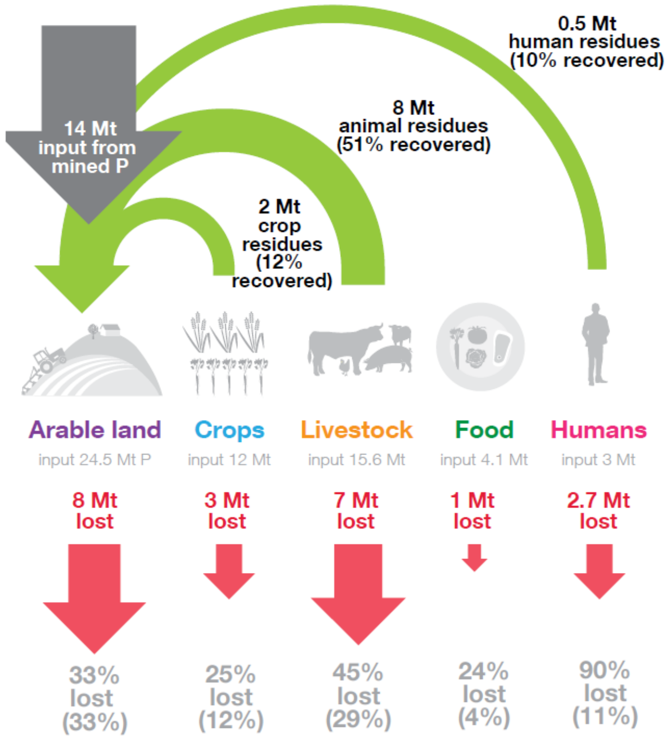


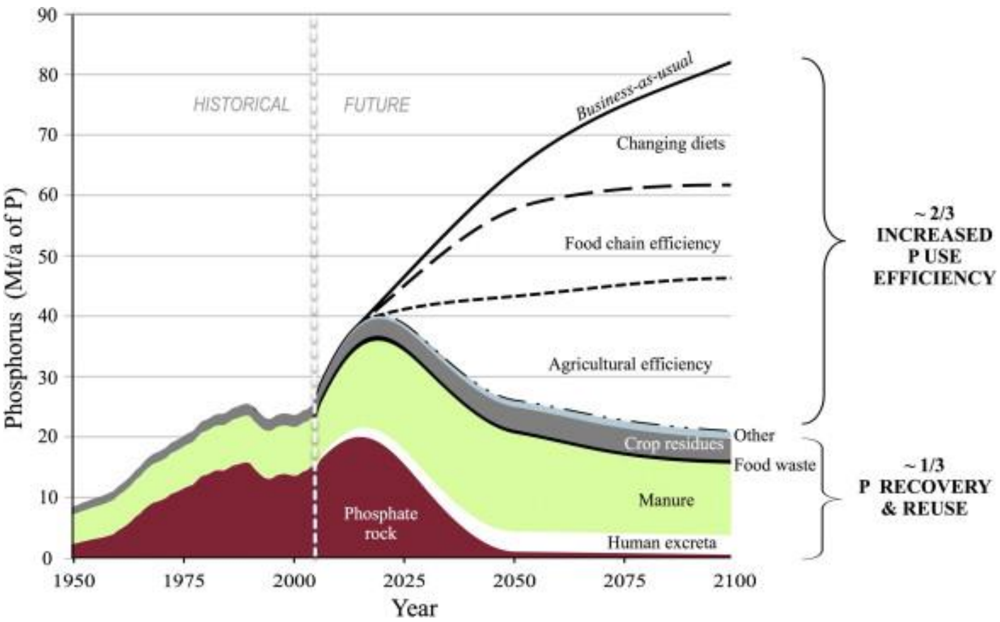

**Figure 4.** Simplified cycle of phosphorus in agriculture based on data from Cordell et al, 2009 and Cordell et al, 2011. Red arrows represent losses into water systems ultimately, and green arrows represent current recoveries into arable land from the different subsystems. The percentages under the red arrows represent the percentage losses from each subsystem, and shown in brackets are the percentage losses relative to the total input into agriculture land. For example, the livestock system loses about 45% of the phosphorus entering the livestock system itself, and this represents about a 29% loss of the phosphorus entering the agriculture system overall. (We have excluded the flow up to the input into farm system, but for example, losses in phosphorus mining and processing can also be significant.)

Source: Tirado and Allsopp, 2012

There are different starting points to improve the resource-efficient use of phosphorus and to close the phosphorus cycle – for a detailed discussion see Rosemarin *et al.* (2011). As

Figure **4.6** shows, the overall potential is considerable. Increased use efficiency, including changing diets, and increasing agriculture and food chain efficiency can reduce the amount of phosphorus needed in agriculture by two thirds. Recovery and reuse can cover the remaining need. According to Cordell *et al.* (2011) in the long run a closed phosphorus cycle could be created that does not require input from phosphate rock.

**Figure 4.6**. **A sustainable scenario for meeting long-term future phosphorus demand through phosphorus use efficiency and recovery**




Source: Cordell *et al.*, 2011

Potential for increased efficiency can start with mining. Efficiency and environmental performance can be improved by new management systems, which can also yield economic benefits, as, for example, the recycling of process water and waste could increase the recovery rate (UNEP, 2011). Currently the recovery rate of phosphate during mining varies widely with a worldwide average of about 65 % (IFDC, 2010). However it is difficult to determine exactly how much improvement is possible as costs and available technologies are very site specific. Other improvements are also possible during raw material treatment, fertiliser production and transportation (Schröder *et al.*, 2010). The treatment of the raw material for further processing did not change much over the last 25 years.

As plant nutrients, including phosphorus, are concentrated in the topsoil, reducing erosion maintains soil productivity and reduces negative effects on water quality (UNEP, 2011). As erosion is connected with so many different environmental issues it cannot be tackled by a single instrument, and indeed its reduction requires different sets of management measures according to local conditions.

The recycling of phosphate-containing materials is the most traditional way of achieving phosphate efficiency. For centuries the use of animal and human excreta was the common way of supplying phosphorus to farmland, but although animal manure is still used in most parts of the world, the use of human excreta has diminished because of health concerns. Today, however, these can be overcome by modern recycling technologies, especially phosphate recycling from sewage sludge, which makes the use of human excreta without hygienic problems. Modern technologies to recover nutrients are evolving, ranging from low-cost, small-scale systems to expensive high-technology ones but these remain costly and currently often uneconomic. Further research and development as well as incentives are need to bring costs down and to solve technical issues, but estimates suggest that were all the EU-15 region's 9 mt of dry sludge reused, it could supply about 23 % of the region's chemical fertiliser need (Rosemarin *et al.*, 2011).

Not only can the phosphate fertiliser industry and agriculture contribute to a reduction of phosphorus by a more efficient use, but consumers can, too, through a reduction in their meat consumption. This arises mainly through a reduced need for feed and feed additives, and thus agricultural products and fertilisers.

As phosphorus is an essential nutrient for fertilisers, the substitution of the chemical element is not possible, but mineral fertiliser can be substituted by organic fertiliser, as discussed above, and this contributes to a closing of the phosphorus cycle. For other uses of phosphorus, substitution is possible – sodium triphosphate as water softener can usually be substituted by zeolite, while the use of sodium triphosphate in laundry detergents is no longer common in Europe. For dishwater detergents research is on-going as current substitutes have significantly inferior characteristics.

### *4.4 Applicability of taxation schemes*

From the analysis of phosphorus' value chain, the following features that could be relevant for taxation emerge:

- there is an overall scarcity of mineral phosphorus;

- the environmental impact of phosphorus use, particularly by the agricultural sector, is high on water bodies;

- EU dependency on international markets for phosphorus is high;

- demand elasticity to price is not high;

- substitutability of phosphorus is very limited;

- there are huge possibilities of phosphorus saving in major applications;

- the present level of recycling is low but the potential is very high.

The main objectives of a phosphorus tax could therefore be:

- securing long-term availability: use should be reduced to the necessary minimum to preserve phosphate rock and to reduce import dependency (input reduction);

- reduction of excessive phosphorus flows especially into water bodies: this can mainly be achieved by a reduction of the use of phosphate fertiliser to the necessary minimum (minimisation of losses);

- closing of the phosphorus cycle as far as possible, reducing input and output at the same time: this can be done mainly by the use of organic phosphate instead of mineral phosphate (increase of recycling).

Besides these quantitative aspects there is also a qualitative reason for policy intervention: phosphate rock very often contains large amounts of heavy metals, especially cadmium, and uranium. Due to environmental and health reasons, the use of these should be reduced.

More specifically, a taxation scheme should aim to:

- reduce demand for phosphorus, in particular non-agricultural applications (especially detergents), but also in agriculture (meat production and energy crops), and improve phosphate rock mining efficiency;

- create incentives to reduce phosphorus losses from arable land, and in livestock systems;

- create incentives to recycle phosphorus (especially organic rather than mineral phosphorus) by maximising the use of phosphorus in manure for soil fertility on croplands and pastures, introducing modern technologies to recover phosphorus from sewage sludge and recovering phosphorus from industrial waste streams;

- create incentives to reduce the use of phosphorus with high heavy metals content.

Given this range of the aims, a tax cannot realistically address them all, and more complex policy packages, including regulation, should be introduced. Nonetheless, the phosphorus sector has been subject to taxation in some European countries, in particular in the form of an input tax generally aimed more, in policy design terms, to environmental impacts than resource efficiency. The experience with these taxes is mixed: most case studies suggest that an optimal taxation scheme to dealing with phosphorus losses has yet to be found. The system in Sweden seems to have been most effective in reducing the use of phosphorus, probably due to the fact that the taxes and charges were sufficiently high, that they were accompanied by action programmes to decrease use, and that there was sufficient potential to reduce phosphorus consumption. The Dutch approach, only to tax phosphorus surplus, was carefully targeted but, surprisingly, results were mixed and, as expected, administrative costs were very high. The examples, however, do suggest that there are long-term effects that result from awareness rising and changes in production structure, and that policy mixes seem to be more effective than a tax alone.

The analysis of the phosphorus flow shows that there is substantial potential to reduce phosphorus inputs even in Europe, which has already reduced phosphate fertiliser use, where the rather low change in use over the last years in the face of substantial price increases suggest that further efficiency gains require greater effort and stronger instruments.

An **extraction tax** on phosphorus mining, given the negligible mining level in Europe and its high import dependency, could work as in the scheme presented in the Appendix I for tax + BTA: demand would decrease but, given the role of the EU in world markets, this could depress the world price with the associated feedbacks on domestic demand in the EU. As the elasticity of demand to price is not high (weak substitution possibilities), the effect would not be strong unless the tax + BTA were very high.

A **material input** tax could either address the input to the phosphate and fertiliser industry – for example, phosphorus acid – or the input to the agricultural sector – for example, fertiliser. As only a few products contain relevant amounts of phosphorus, the determination of the tax base is rather simple and European experience has shown that such a tax is practically possible.

The main expected outcome of an input tax is the reduction of demand. Since an important part of the phosphorus cycle takes place within the agricultural sector with decisions on fertilisers use taken by farmers, higher fertiliser costs might give incentives to avoid phosphorus losses, close the phosphorus cycle and thus indirectly reduce the demand for phosphate fertilisers and phosphate rock. A price signal can also be helpful to support the introduction of new recycling technologies and to support agricultural management methods that close the phosphorus cycle and reduce erosion.

Experience of phosphorus taxation does not include BTAs on imported products containing phosphorus – for example, food products. Furthermore, the analysis has shown that, given the relatively low elasticity of demand to price, the tax would have to be very high to trigger a change in phosphate use. If phosphorus saving and recycling do not take place, product prices will increase and the competitiveness of the European agriculture sector may decrease. In a world with rather free agricultural trade, this could be an obstacle for such a tax. Taxation alone may be not enough because complex agricultural management structures have to change for which supplementary instruments would be helpful. Experiences in Europe have pointed out the necessity of complementary policies to stimulate innovate technologies for phosphorus recycling.

A final **consumption tax** on direct phosphorus content would cover only a few products. An example could be the taxation of detergents, but that would not affect a significant share of phosphorus use. In this case, however, taxation would be rather simple and incur only moderate administrative costs as the phosphate content of a detergent can easily be determined. The development of phosphate use has shown that other instruments – voluntary actions to reduce phosphate in detergents or regulation on phosphate content – has already had strong effects on phosphate use. It is questionable whether an economic instrument really would render a more efficient outcome on such a small market with a limited number of products.

Beside a direct consumption tax on products containing phosphate, a tax on products whose production requires phosphate could be taxed. One example would be meat. Although it is very difficult to determine the exact amount of phosphate required for a kilo of meat, there are already discussions on targeting phosphate e.g. on the reduced VAT rate for meat that picks up very indirectly the issue of phosphate.

A tax on phosphorus or the phosphorus content of products presents implementation issues – it would be difficult to influence all uses of phosphorus and not all options to improve phosphorus use can be targeted by a single instrument. Probably a tax on phosphorus could complement other instruments that improve phosphorus efficiency, so a tax could be part of a policy mix. In this regard, it is necessary to consider current evolutions in agricultural policy. While there are incentives that increase agricultural demand, especially biofuel policy, and subsidies to agriculture are still very high, it would be possible to redirect these policies to curb additional demand for phosphorus, help to close the phosphorus cycle, support avoidance of erosion and reuse of manure.

# 5 Considerations for other non-renewable resources

The three case studies highlight important aspects of possible taxation schemes, but the conclusions can only be partly generalised to other metals/materials, for which other factors may be important. However, without extending the conclusions of the case studies to other resources/materials, we briefly discuss below some issues that could emerge in designing and implementing taxation schemes for other resources/materials[35].

Aluminium is very important for the European economy, but supply is not limited. Somewhat similar to iron, its main environmental impact is through energy use during production and possible efficiency improvements could probably be obtained by higher recycling rates. Substitution with other materials is also possible but not necessarily advantageous – see the discussion on copper. However, as aluminium is light, its use could increase in the future as a substitute for heavier materials bringing environmental advantages of lightness, for example in transport. A practical implementation of a tax is quite challenging because aluminium is widely used, traded and recycled. In many respects an analysis of a tax on aluminium can be expected to be more or less similar to that on copper or on iron.

Zinc is not in short supply but the environmental impacts of its supply can be quite high, depending on the mining and transformation technologies used. Recycling is currently rather low, but because of zinc's dispersed use there is only limited potential to improve reuse. For some applications efficiency improvements are possible, for others, for example in the chemical industry, the metal is essential. As it is widely used in alloys for many finished and semi-finished products, often in rather small quantities, the determination of a tax base would be very demanding. A reduction of its extraction might also reduce the availability of other materials such as indium that are co-products of zinc mining. In light of all these factors, introducing a tax on zinc would be very challenging and its assessment difficult.

Platinum-group-metals (PGM) are somewhat critical in terms of supply. The EU is completely dependent on imports, 60 % of which come from South Africa. As the ore concentration is rather low, the environmental impact of mining is not negligible. These metals are mainly used for two purposes: in rather essential, and environmentally important, applications such as catalytic converters, where the price elasticity is rather low as there are no or limited alternatives; and secondly for jewellery, where price effects are ambiguous. The main need for action seems to be an improvement in recycling, and the demand effects of a tax are unclear.

The supply of indium is limited as it is a by-product of other base metals but demand may increase considerably. If its price is high enough it will be recovered during the extraction/industrial process, otherwise it may end up in tailings. As it is a by-product, it is difficult to allocate an environmental impact to it. Currently there is no possibility of substitution as it is essential to the production of displays and solar panels. As indium is a by-product, a reduction of mining would only have a marginal environmental impact. A tax might reduce demand and/or exert pressure on the price of virgin material, rather than recycled material. This suggests that a specific tax on indium, like other by-products, would be a weak instrument. Improvements in recycling indium, current rates are almost zero, should be addressed with other more targeted instruments

[35] Sources used for the following discussion are USGS, Commodity Statistics and Information; EC (2010).

The supply of rare earth metals is highly critical as there is basically only one main supplier, China – mining in other parts of the world is possible but more costly. The environmental impact of their mining is rather high. Rare earth metals are essentially used in special applications, particularly in environmental technologies such as electric vehicles or wind turbines. Substitution is technically possible but leads to inferior products, less efficient electric motors, for example. Rare earth metals are disputed as a trade issue as China itself taxes them and tries to limit their export[36]. As rare earth metals are so important for future technologies and demand may increase considerably, a geographical diversification of the sources of supply is likely to emerge, together with an increase of the recycling which is currently almost non-existent. A deeper analysis of a possible tax might be of interest. However, the need for rare earth metals in environmental technologies is high and thus a price increase, brought about through tax, could be detrimental to the further spreading of these technologies and, most importantly, recycling rates can be much better targeted with mandatory requirements and other instruments.

Cement and aggregates are somewhat different from the other materials discussed here, as they are not chemical elements. Ingredients for cement are not limited in terms of supply, but the material flows associated with cement are massive and its environmental impact during production and use is high. The main environmental concern is energy use and carbon dioxide emissions during the production process, but its use in building infrastructure causes land-use change, with considerable environmental costs. As a result, there are good reasons to reduce cement use to more sustainable levels. Cement is not extensively traded and what trade there is can be easily identified – there are not many products that contain cement – and therefore a tax within an international context would be relatively easy to implement. A tax on cement should be considered alongside a tax on aggregates – sand, gravel, and crushed rocks – which are a main input for cement production. Extraction and processing of aggregates have direct and indirect environmental impacts, but they are not extensively traded because transport costs are high compared to the value of the goods. Taxes on aggregates have been examined in other works[37]. Taxation of aggregates can induce substitution by construction and demolition waste (recycling) within construction materials, as has, for example, happened the UK. If the government aims to use less cement and aggregates it should first revise its procurement policy for infrastructure and technical requirements in contracts for public works.

This short overview provides a mixed picture. Rather unsuitable for taxation seem to be materials that are by-products of mining (indium), difficult to substitute (rare earth metals), or can have an unclear demand reaction to taxation (PGM). More promising for designing and implementing taxation schemes for resource efficiency seems to be widely used materials, like aggregates, as there are possibilities to improve resource efficiency through their substitution with other materials or recycling. On the other hand, taxes on widely used materials may raise questions regarding their practical implementation.

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[36] See http://www.mineweb.com/mineweb/content/en/mineweb-political-economy?oid=152605&sn=Detail

[37] See EEA, 2008

# 6 Discussion and conclusions

Economic instruments gained importance in environmental policy in recent years. Environmental taxes are now considered as instruments both to internalize external costs and to create incentives for increasing resource efficiency, thereby reducing resource use and import dependency. These economic instruments can also contribute to the transformation towards a more sustainable economy by shifting the tax burden from labour to the environment when they are integrated into green fiscal reforms (EEA, 2011a; 2011b; 2014). Experience of economic instruments aimed at reducing emissions and environmental impacts already exist, for example, in the case of energy (carbon taxes) and aggregates. It, therefore, seems reasonable to explore the possibility of applying such instruments to other non-energy, non-renewable resources within a strategy for increasing resource efficiency. Implementing a tax for non-energy resources, however, is not as straightforward as it is for energy/emissions. ETC/SCP (2012) made a first analysis and presented general rationales for resource taxation, but also presented practical issues that emerged on the taxation of non-renewable resources or raw materials. In this paper we have looked deeper into the possible outcomes and implications of material resource taxation with the help of three case studies: iron and steel, copper, and phosphorus.

As mentioned, there are different reasons for material resource taxation. In this paper, such taxes are not considered in the context of revenue generation or optimal taxation of resource rents. Instead, the focus is on the influence of a tax on the demand for material resources, aiming to increase resource efficiency in general and promote recycling (EC, 2014b). In addition, as the extraction, industrial transformation, use and disposal of the resources have environmental impacts, the reduction of resource use, import dependency and the negative environmental effects of extraction and use are considered as main rationales for a resource tax. Means of achieving these objectives are, above all, an increase of resource efficiency in production, substitution of resource-intensive materials and resource efficient product design, higher and better recycling, and more sustainable consumption patterns. The question is how far a tax on resources is an appropriate instrument to achieve these desired effects and what levels of the value chain should be best targeted by taxation to increase the effectiveness of the policy instrument.

### Taxation at different stages of the value chain

In theory, whatever the point of application of a tax on a material resource within an industrial value chain – extraction, industrial input, final product – the result would be to increase the price of and decrease the demand for the taxed material resource because the tax would be transmitted along the value chain itself. In practice, however, a material resource tax can have different effects depending on the phase of the value chain it is applied to. At different phases of the chain the reaction can be differently effective with respect to the taxation objectives because of the variety of possibilities of induced innovation and material demand strategies by industrial or other actors taking decisions at that phase. In particular, demand elasticity to price, and then to the tax, and market power, which is relevant for the transmission or absorption of the tax, can vary at different phases of the same value chain[38]. Specific value chains can therefore require different taxation approaches and designs. This

[38] In this paper we did not perform a full tax incidence analysis, i.e. the way a tax on one input is actually transmitted to the subsequent phases in the sectors considered, which would have required the use of formal industrial-sector models. The analysis has been mostly on the expected equilibrium outcome of a tax introduced at different stages of the value chain for the material, see also the Appendix I.

paper distinguishes, for a single non-renewable material resource, three stages of the chain at which the application of a unilateral tax – one introduced by a single country/region – is possible:

i. extraction;
ii. input of the material at the first industrial use;
iii. final consumption of products embodying the material (ETC/SCP, 2012).

Given that there are only limited mining activities within the EU, especially for metals, a unilateral domestic **extraction tax** by a country/region that is net importer of the resource, as the EU, will directly involve international trade effects. The tax will put domestic producers at a cost disadvantage compared to foreign producers and there will be a reduction of domestic extraction, an increase in imports, and a total demand reduction that will depend critically on demand elasticity to price. Increasing imports will lead to mining leakage to other countries, the net resource effect of which can be nil in terms of the extracted resource, and the net environmental effect can possibly be negative if the technologies used abroad are worse than domestic technologies. As is well known from other sectors, the results could be a domestic economic loss and, possibly, a global environmental loss.

A BTA on imported minerals related to the tax can be needed, together with export refunds, for domestic exporters to protect the domestic taxation policy. The effect of a BTA can neutralise the effect of the tax on domestic producers, but its global effect on demand will depend on the size of the taxing country in the world market: if the country is a large importer, a reduction of global demand will prevail that could reduce the world price and as a result reduce the final demand less than in the case of a small trading country. The size of these effects on demand depends, in any case, on elasticity of demand to price. The three cases considered, for iron and steel, copper and phosphorus, as well as more general evidence, indicate that the demand of minerals to price is low – they are largely non-substitutable inputs in subsequent transformation phases. Therefore, the extraction tax would have to be very high to achieve a global reduction in extraction – possibly through a price effect on downstream phases of the material production/consumption chain – otherwise the final effect on extraction demand could be very low.

A different outcome could be expected from a global, multilaterally-agreed extraction tax, rather than a unilateral tax imposed by the EU or single countries. Such a tax would eliminate international spill-over effects, BTAs would not be needed, by creating an internationally homogeneous extra cost for using the resource and an overall demand-depressing effect (Appendix I). However, where a global tax were on just one resource, for example iron ore, it will stimulate substitution effects that could be very uncertain in terms of global resource efficiency.

A **material input tax** is imposed the first time a material from a non-renewable resource enters an industrial use. Some examples already exist in Europe for phosphorus. Its level of application for metals can be the input of refined or semi-finished metal products into industrial processes, for example, manufacturing. An input tax does not discriminate between domestic and imported materials and therefore it does not need a specific BTA. It would, however, have to be complemented by a BTA on the material content of imported intermediate and final products, which would bring with it a high administrative burden. In order for a material input tax to be easily implementable, the main practical requirement seems to be that the variety of products subject to the taxation is not too high. The analysis has shown that this could be the case for phosphorus, since it is mainly used in fertiliser.

The main difference from an extraction tax, which is an output/supply tax, is that a material input tax is expected to directly and negatively affect the demand of the input in industrial or other applications through a reduction in the profitability of using the input itself. The possible effect on demand of the material, and then of the resource, will largely depend on demand elasticity to price, which reflects the possibility of substitution with other materials or with recycled secondary materials in industrial applications, as well the possibility of material saving through innovation. The case studies suggest that price elasticity can be very different between metals. In any case the possibilities of substitution/saving are more likely to exist in industrial processes for complex products than at the mining/metallurgical stages. Actually, material competition/substitution and material savings are common practice in many industrial applications, especially in the long run when product, process or design innovation can be better deployed. However, the case of metals and phosphorus illustrate that, in general, substitution can be constrained in practice, even if the price of the material is very high. Techno-economic constraints also emerge for the substitution by recycled secondary materials. Each material has specific features – for example, low substitutability for steel and phosphorus, already high recycling for metals – which can be relevant for the effectiveness of an input tax.

Substitution and recycling also poses two main issues when taxation addresses a single material:

i. the substitute, such as aluminium for copper, can be resource and energy intensive, which could impair the overall taxation policy outcome;

ii. recycled material cannot be easily distinguished from the virgin material.

Coupled with the need to identify the material content of traded intermediate and final products, these issues raise significant challenges to the practical implementation of a material input tax.

Even though the **taxation of consumption** of products that use specific resource intensively is possible, its application can be challenging and its effectiveness is uncertain. The technical implementation is, in principle, rather easy because there is a long tradition of different consumption taxes, for fiscal revenue reasons, and, within certain limits, even a single country within the EU could implement such a taxation scheme. If products are taxed at domestic consumption, export refunds are not needed on international trade. There can, however, be significant problems with the identification of the intensity of a specific resource within a product, which can make the taxation base uncertain. If data are not available in the necessary quality, this tax would require rough proxies that could be controversial and prone to technical debate and lobbying. In the case of metals in complex final-consumption products, their share of production costs and final price can be very low, for example in luxury cars, thus preventing consumers perceiving the tax burden or providing an incentive to switch to other less intensive products. Furthermore, consumers could reallocate expenses to other non-taxed consumption goods that can be as intensive of non-taxed resources. Taxation at this stage, therefore, can be better thought of as a tax based on the intensity of multiple resources, possibly from an LCA perspective.

In the case of simpler products, such as dish detergents that use phosphorus, the implementation of a consumption tax might be administratively possible. Since only a very small fraction of phosphorus is used for this purpose, however, it is unlikely to have much influence on overall phosphorus use. If, on the other hand, final agricultural products like meat were chosen for taxation based on embodied phosphorus, a much larger share of overall phosphorus use would be covered, but the impact on its use could be unspecific and the weight of the tax on the price of the intermediate and final product could be low, thus preventing substantial behavioural change. In all these cases, the final reduction of resource extraction and use can be very limited.

In Table 6.1 the main expected implications of a taxation scheme at each of the three levels are summarised.

**Table 6.1. Implications of a tax for resource efficiency imposed unilaterally by a country or the EU, according to the level of application (relevant case studies in square brackets)**

| | Level 1<br>Resource taxation | Level 2<br>Material input tax | Level 3<br>Consumption tax |
|---|---|---|---|
| Tax basis | Taxation per unit (quantity) of resource extraction (output tax) | Taxation on the resource-based material (quantity), either domestic or imported, at its first use (input tax) | Taxation of consumer products, either domestic or imported, based on their resource content/intensity (final consumption tax) |

| | | | |
|---|---|---|---|
| Expected impact | Tax without BTA: reduction of extraction mainly domestically, with mining leakage abroad [iron ore, copper ore]; economic cost domestically, global resource/environmental effect nil or negative | Reduced demand for the material input in industries through: (i) material savings [phosphorous]; (ii) substitution by other materials [copper]; (iii) increasing recycling [iron/steel, copper].<br>Innovativeness of the using industry is critical for the substitution/saving/ recycling effect [iron/steel, copper].<br>The negative effect on demand will be net (both domestic and international), but it will be more uncertain (lower/higher) if the taxing country is a large economy | To reduce the consumer demand of the resource-intensive product by: (i) consuming less; (ii) substituting with other final goods.<br>The effect will critically depend on consumer perception, and the possibilities of substitution (elasticity of demand) |
| Requirements in implementation and administration | BTA on imported minerals, export refund for domestic producers needed to avoid international leakage; with tax + BTA reduction of mineral demand, mainly on international markets [iron ore, copper ore]; the effect on demand will be more uncertain (lower/higher) if the taxing country is a large player in the world market for the resource | BTA on the material content of all products imported to avoid the tax is bypassed/weakened through increasing trade of intermediate/final products<br>Avoid risk of taxation of recycled materials input [copper, iron/steel]; need of material tracking systems | Definition of resource intensiveness of domestic and traded products (one resource or more resources)<br>Need to avoid taxation of recycled inputs in final products |
| Uncertainties, open issues, side effects | Easy to apply, but little domestic mining activities in the EU<br>Low elasticity of demand to price/tax for mineral inputs (low substitution possibilities) will make the effect on extraction (reduction) very limited | Elasticity of demand to price is critical; if it is low, the demand/supply reduction effect can be low [iron/steel, copper, phosphorous].<br>Substitution can be in favour of non-taxed resource-intensive products [iron/steel, copper]<br>Material input costs in total costs could be too low to trigger innovation/substitution and then high tax rates is needed [iron/steel]<br>Recycled materials are not easily distinguishable from virgin materials [copper, iron/steel]: risk of taxing recycling<br>Very demanding in information on material content of all products to apply a BTA on imported products | Very uncertain definition of resource intensive products and related measurements<br>Non-taxed substitute goods demanded by consumers may be environmentally intensive (e.g. energy intensive)<br>Material costs in total costs could be low (e.g. luxury goods); taxation must be very high to be perceived by consumers and trigger reactions |

## Cross-cutting issues

*Potential for efficiency*

The case studies point to the existence of potential for resource efficiency improvements at different phases of the value chain. For example, the use of high-strength steel in construction activities leads to less material being used for the same purpose, while much of the phosphate used in agriculture is currently lost. Taxes on resources/materials can contribute to improve resource efficiency through higher costs and higher prices creating incentives for their efficient use. As the example of the fertiliser tax in Austria suggests, the long-term impacts may be more significant than immediate results suggests. In Austria, it raised awareness of the environmental impacts and cost of fertiliser use and lead to long-term changes in production structures. Despite of the shortcomings that emerged from the overall analysis, taxation can be a good candidate to trigger mechanisms that achieve efficiencies.

*International trade and global effects*

In a world connected through trade, unilateral taxation of any material resource in any country/region has to take into account global spill-over effects. As can already been seen for carbon/energy taxation and EU ETS, leakage effects have been extensively discussed and policies adjusted accordingly. The same risk of mining or metallurgical leakage emerges for unilateral resource taxation. Taxes may endanger competitiveness of industries and high taxes may lead to industries moving to countries with lower resource prices, or simply no taxation. In the worst cases, the environmental effects can be negative if production moves from countries with higher environmental standards to countries with lower ones.

The use of BTAs or equivalent trade policy instruments is therefore suggested, at least for traded primary resources and materials. A BTA is needed in the case of a resource tax[39], while a material input tax requires a system of BTA and export refund on all traded product based on their material resource content. Furthermore, the effects of BTA may be complex and not necessarily lead to a net resource demand reduction if the country/region adopting it is a large importer on the international market, as is the case with the EU (Appendix I).

In practice, a scheme based on tax + BTA might be technically difficult to implement because of possible political complications including trade policy controversies, and the need for huge amounts of data on material resource use in products. For metals, for example, it is highly uncertain whether the necessary data could be made available with reasonable administrative effort. An approach based on global or multilateral resource taxation can be better.

*Tax base*

We have not discussed the technical aspects of the selection of the tax base in depth, and have simply adopted the weight/quantity of the material resource as the tax base[40]. If material resource taxation, while preserving resource-efficiency, also looks at the environmental impacts of extraction/use, the tax base could be different. A possibility could be that in a resource-taxation scheme (Appendix I) the tax is proportional to resource/environmental externalities produced domestically, while the BTA is proportional to the (embodied) resource/environmental externalities of the production at foreign extraction sites. This kind of BTA would, of course, require extensive information on technologies in foreign countries. However, with this approach to tax + BTA, if the environmental features of extraction technologies in Europe were better than those in foreign countries, which is often the case, the results could even be an increase in mineral production in Europe. With reference to Appendix I, this would be the case of a BTA higher than the tax, which would imply that domestic producers would produce more than before the taxation scheme was introduced because the higher BTA, reflecting the difference in domestic (lower) and foreign (higher) externalities, would be equivalent to a net tariff on imports.

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[39] A domestic unilateral extraction tax without BTA can be the worst solution from an economic and environmental point of view, see the Appendix I.

[40] The tax base selection can be important; for example it makes a great difference if the base of a resource tax is the weight of the mineral or the metal content.

*Tax rates*

To stimulate innovation by industrial users or consumers, tax rates need to be sufficiently high no matter the phase of the chain at which the tax is introduced. The case studies and other studies in literature show that many materials have rather low price elasticity of demand. Material costs often constitute only a limited part of the overall costs of an intermediate or final product while a change of the material input might incur considerable costs in the short run in, for example, product development, change of processes, etc. Material costs are very often outweighed by factors such as manufacturing costs, energy use or wages, as the case study on iron and steel shows. Another reason for low price elasticity may be a limited substitutability due to technological constraints or safety and environmental standards. Platinum-group metals can provide an example by being mainly used for two applications – catalytic converters, where the price elasticity is low as there are only limited or no alternatives, given the present state of technology - and for jewellery, where price effects are ambiguous. The case studies suggest that taxation will have to be at very high to have any real effects. These high rates, however, may cause considerable economic changes and adaptation costs in the concerned sectors while the resulting resource and environmental benefits have to be carefully measured. In addition, most global material resource markets are very unstable and international reference prices fluctuate significantly, even in the short run. Therefore, tax rates and the whole taxation scheme should be designed in a dynamic way so as to create incentives to saving/substitution/recycling that are more stable than the material price cycle.

*Substitution*

Particularly in the case of resource input and consumption taxes, the possibility of substitution of the taxed material/product is central to the effectiveness of the tax, but, at the same time, this can be also a major shortcoming of a tax scheme addressing a *single* material resource.

Without substitution possibilities along the value chain, the tax will trigger a cost/price transmission mechanism up to final consumer – basically equivalent to a final consumption tax. With substitution possibilities in industrial processes, the case studies on metals highlight opportunities and limitations. In recent years there has been a substitution of copper by aluminium in some applications, for example, motivated by the strong increase in copper prices relative to aluminium. However, as material substitution always entails some form of innovation, aluminium substitution for copper is unlikely in any applications that require the substantial re-design of a complex final product; this is likely only in the longer run.

Nevertheless, the effects of substitution caused by one-material taxation can be ambiguous because:

i. taxation of a single metal/resource might just have substitution effects without overall resource efficiency gains;

ii. substitutes of the taxed materials may have environmental disadvantages – higher energy intensity or emission intensity, for example.

The effects on substitutable materials, therefore, have to be considered when taxing one single material resource.

Taxing clusters of materials would, in principle, be a better approach because it reduces the risk of undesirable substitution but would make a tax much more complex to implement and may simply shift the problem to the level of material clusters, such as plastics *versus* metals, instead of single materials, copper *versus* aluminium, for example.

*Material saving innovation*

A different set of outcomes can be expected from material saving innovation possibly triggered by taxation. A tax – especially a tax on a material input – could stimulate, instead of substitution by other materials, technological solutions aimed at saving the taxed material itself in a given product function, downsizing, for example. Although this kind of reaction to a tax can be very favourable to resource efficiency, it must be noted that:

i. material-saving innovations could be unavailable, or at the research and development or patents stage, and their full development and application thus require investment that must be justified by the level of the tax. Effectively, the less commercially mature the material saving innovations are, the higher the tax should be to trigger their full deployment;

ii. given the complexity of material-intensive manufactured products – cars, consumer electronics, etc. – it is unlikely that material saving innovation will not require a degree of product redesign, and can have unpredictable net effects on material choice and mix, thus bringing back to the issue of substitution and/or relative environmental pressures from substituting materials;

iii. downsizing and miniaturisation, the use of nanomaterials, for example, are often the outcome of far-reaching technological trajectories, on which the possible influence of a tax on conventional materials is very difficult to detect.

On the other hand:

i. while a tax, itself, would have be very high to economically justify material saving innovation, given that innovation in material-intensive manufacturing products is a continuous process, a tax on certain materials could be an important focusing device, giving rise to a different orientation of the design process, possibly in the direction of material saving, without excessive cost;

ii. in spite of the complexities highlighted above, manufacturing industry, given its innovation capacity, is the actor in the value chain best positioned to activate material-saving innovation in response to a material tax, and then the level of the value chain at which the tax is introduced can matter.

*Recycling*

Improving recycling is a central point in resource efficiency policy. It is also a central point in the strategy for developing a circular economy, adopted in 2014 by the European Commission (EC, 2014b). Taxation schemes based on input or consumption taxes must be designed so that only virgin materials, and not their recycled equivalents, are taxed, which can pose design challenges for taxes on metals. Assuming that only virgin materials would be taxed, this could create an indirect incentive to use of recycled materials, which will be a specific form of substitution (Appendix I).

An issue common to many metals, steel and copper were examined here, is that their recycling rates are already quite high in many countries. A further increase, stimulated by a virgin material tax, could involve increasing marginal costs and the latter can be covered only if the tax rate is enough high to stimulate significant discrimination against virgin materials so that recovery and recycling of more dispersed scraps becomes profitable. There can be an environmental justification for recovering these marginal high-cost scraps in that, being dispersed, they can have higher environmental pressures.

In these cases, as well as in the cases of metals that have still low recycling rates, a taxation scheme could be designed in a way that explicitly addresses recycling by joining a tax on virgin metals and a subsidy on its recycling. The approaches could be:

i. to apply an input tax on virgin metal, for example, at the semi-manufacturing stage, combined with a full exemption for old scrap inputs;

ii. to use the revenue from a tax of virgin metal to subsidise the production of recycled metal or the use of old scrap instead of virgin metal. Such a scheme is sketched in Appendix I. The technical possibility of such an approach could exist up to the level where the material inputs are accountable and scrap, as an input, could be fully identified.

As the case study on phosphorus shows, closing the phosphorus cycle could be a target of a tax. A sufficiently high price increase of phosphate rock or fertilisers could create incentives not only to reduce phosphate losses but also to recycle more in traditional ways as manure or to introduce modern recycling technologies that, for example, extract phosphorus from sewage sludge.

Tax-related incentives for recycling can be added to existing indirect incentives for recycling. The production of aluminium from bauxite or iron from ore, for example, is significantly more energy intensive than recycling. The EU ETS and carbon taxation schemes therefore provide indirect incentives for recycling. This example also highlights the links between different policies that can be relevant for resource taxation.

*Links to other policies*

The analysis has shown that, for many materials, there are strong links to other policies. The energy consumption of metal production, for example, is very high at all levels of the chain, and, indeed, the iron and steel sector is a major contributor to greenhouse gas emissions. This suggests that any policy that targets the environmental impacts of non-energy resource consumption should always tie in with energy policies, and that energy policy has an impact on the use of other resources. Furthermore, the case study on iron has pointed out the strong link to European steel policy and the case study on phosphorus has made the strong link to agricultural policy clear. In both policy fields, the EU supports the respective sectors with high subsidies and/or action plans to secure their competitiveness and boost production. The case study on copper has pointed to the incentives for recycling that are provided by waste policies such as the WEEE Directive. This suggests two important things:

i. any instrument that deals with the resource efficiency of materials raises issues of coherence with the existing policies in corresponding sectors;

ii. in order to be successful, the goal of improving resource efficiency has to trigger changes in other policy domains, especially with the aim of reducing environmentally harmful subsidies.

A tax on resources/materials is, therefore, only one of a range of instruments that can provide incentives for resource efficiency improvements. In the case of phosphorus taxation in Sweden, for example, the literature suggests that action programmes to decrease the use of fertilisers had a major effect. Very often, policy mixes are more effective than a tax alone, especially bearing in mind the rather low price elasticity of many materials.

*Global-level taxation*

Even under trade-neutral taxation schemes based on tax + BTA, it is not easy to envisage unilateral European taxation on a *single* material resource. In this case, the conditions for effectiveness on resource efficiency would be rather stringent:

i. taxation should reduce extraction/consumption without substitution or increasing the use of other minerals/metals/materials, an outcome critically dependent on the technical possibilities of net material saving and innovation, and/or:

ii. taxation should stimulate substitution of the targeted material by relatively less scarce - and less polluting - minerals/materials, and/or:

iii the resource efficiency effects of taxing just one material resource should be relatively higher than the resource efficiency - and environmental impacts – of substitutes.

If these conditions do not apply, a unilateral tax on a single material will raise the risk of just ending up with cross-material substitution effects with uncertain resource and environmental implications and international spill-overs, possibly with sub-optimal effects on recycling.

A global multilateral extraction tax addressing all non-renewable non-energy resources (Ekins, Meyer and Schmidt-Bleek, 2009) could be interesting to consider (Appendix I). Its expected effect would simply be a world price increase, leading to a global demand reduction for all resources. Leaving aside the fact that it would be politically extremely difficult to achieve, the design of such as tax would be far from simple. For example, purely to eliminate substitution effects and undesired international spill-overs, its rates would have to be differentiated by material resource according to some criteria – possibly scarcity, or environmental impacts in the life cycle. Even then, the price elasticity of demand of each resource would be relevant to the effect on global resource demand.

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EUROFER
www.eurofer.org

European Environment Agency – Indicators Website

http://www.eea.europa.eu/data-and-maps/indicators

Eurostat Waste Data Centre
http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/database

ISSB Iron and Steel Statistics Bureau
http://www.issb.co.uk/eu27.html

MEC Minerals Education Coalition
http://www.mineralseducationcoalition.org/minerals/iron

USGS U.S. Geological Survey, Commodity Statistics and Information

http://minerals.usgs.gov/minerals/pubs/commodity/

World Steel Association
www.worldsteel.org

# Appendix I: Market effects of resource taxation

The effects of a unilateral tax, combined with a BTA, in open economy have been extensively studied in the case of carbon taxes and the possibility of a BTA has been studied with reference to EU ETS – quantitative measures with effects on prices/costs. Different types of complex model, sometimes computable general equilibrium models (Gros, 2009), have been employed. These highlight the possible complexity of effects arising from a unilateral tax on both the adopting country and the rest of the world. Far less developed is literature on the effects of unilateral environmental taxes on intermediate inputs (Poterba and Rotenberg, 1995).

In this appendix, we present very simple partial equilibrium (single-market) schemes for the effects on a material resource of a unilateral tax imposed by a country/region open to international trade that is a net importer of the material resource[41]. The schemes are variations of standard schemes of the effects of a levy/tax as a trade policy instrument (Krugman and Obstfeld, 2006). The main aim is to depict, in a very simplified way, the basic effects of a tax, be it coupled or not with a BTA, on a material resource market in terms of domestic supply, trade, price, total demand. The analysis of the resource tax also encompasses the effects of a global tax on extraction/consumption on global market equilibrium.

The schemes address taxation at the three different levels of the value chain – extraction, material input in industry and resource-embodying final good – considered in this paper. Given the importance of substitution and recycling as possible effects of resource taxation, this appendix also includes a simple scheme of market equilibrium for material substitution and recycling with a tax. This should allow the highlighting of theoretically predicted similarities and differences between these three levels of application of a resource-related tax.

The analysis is at the aggregate market equilibrium level and based on a comparative-statics approach and does not give a detailed account of the possible inter-sectoral effects of the tax/BTA through tax transmission *via* prices along the value chain (tax incidence), which would require inter-industry analysis – for example, input-output or industry-level engineering models. We do not discuss the aim of the resource-related tax, which has been covered in the text. The tax considered is a fixed amount tax, similar to an excise tax that would simply be added to the price/cost before tax[42]. The possible use of the tax revenue is only explicitly considered in the case of recycling. Finally, we do not develop a welfare change analysis – gains and losses in terms of producer and consumer surplus as well as tax revenues. We use a mineral/metal as reference materials.

***Resource extraction (or supply) tax***

*Small economy*

The equilibrium of the domestic mineral market, for example, iron ores, of a net importing country/region is represented in Figure A.1 by the usual demand and supply curves of a competitive market, representing respectively the marginal benefit of mineral demand for metal production or net

[41] The EU is a customs union (i.e. no tariffs/limitations are imposed on goods exchanged within the EU and Member States impose a single common external tariff on goods/services imported into the union; from a trade-policy point of view the EU can be seen as a single country. Furthermore the EU is a net importer of resources/materials.

[42] If applied to the price (P), it would imply a price after tax PT = P + T. An *ad valorem* tax, would instead imply PT = P(1+T).

profits, and the marginal cost of supplying the mineral. The scheme is referred to a 'small economy', that is a country whose demand is unable to influence the world market price, the latter being exogenous to the country itself[43]. The domestic mineral market equilibrium in autarchy would be the point Ed. Given that the country is fully open to international trade, it can import an unlimited amount of the mineral at the world price (Pw), and the equilibrium price in the domestic market would be the Pw. At a price Pw, the equilibrium domestic demand is D0 and it is satisfied by domestic supply Sd0 (until domestic marginal production cost equals Pw) plus import by an amount IMP0 - the latter then corresponding to domestic demand minus domestic supply.

Now suppose that a tax (T) on mineral extraction (supply) is imposed on each unit of mineral extracted/supplied from domestic mining only (extraction tax). This is equivalent to an increase T of the marginal production cost of the domestic mining industry, and the supply curve will shift backward in proportion to T. Given the equilibrium price Pw, which will be unaffected by the tax on domestic extraction only, this increase of cost will bring the domestic supply to be reduced to Sd1. The domestic equilibrium demand will not be affected (D1=D0) and imports will increase by an amount corresponding to the domestic supply reduction, thus becoming IMP1. The only effect of T without other adjustments will just be substitution of domestic supply by imports, with damage to the domestic mining industry and no effect on demand or equilibrium price.

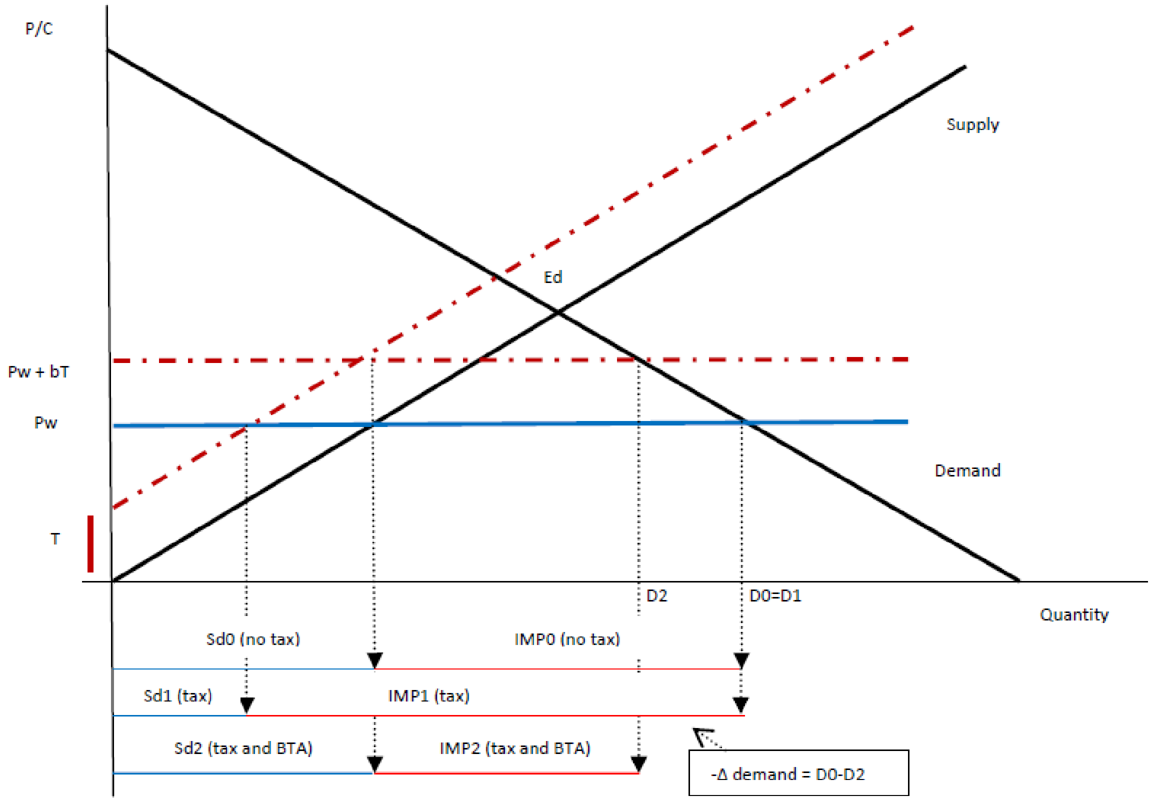
If a BTA of an amount equal to the domestic extraction tax (bT=T) is imposed on each unit of mineral import, the equilibrium price in the domestic market will shift upward because imported minerals will be sold at a price Pw+bT and this will be the new price faced by all the suppliers in the market (domestic and foreign). (The country is net importer and we do not take into account a tax refund on exports). At the new equilibrium price P+bT there will be two main effects: (i) domestics supply will increase to a level Sd2 equal to the initial level Sd0 without T (the higher price Pw+bT is such that supply is profitable up to Sd2=Sd0 and the effect of T will be neutralised); (ii) the market equilibrium price Pw+bT is higher than without tax plus BTA, and then total demand will be reduced to a level D2, with a net demand reduction of D2-D0; (iii) import will be reduced by the same amount D0-D2 to a level IMP2.

Then a domestic extraction tax coupled with an equal BTA level will leave the domestic mining industry unaffected, will increase the equilibrium price, and will reduce demand and imports[44]. The effect on price and demand will be proportional to the level of the tax/BTA (for a given elasticity of demand). This outcome is, in terms of resource/mineral demand, better than the initial equilibrium without tax + BTA. The worst policy would therefore be a domestic extraction tax without BTA because it would cause just import penetration, which corresponds to increasing foreign supply and then leakage of extraction, economic damage to the domestic mining industry, and no decrease of resource/mineral overall demand.

**Figure A.1. A unilateral tax (with/without BTA) on the extraction of a mineral resource in a 'small economy' open to international trade (net importer)**

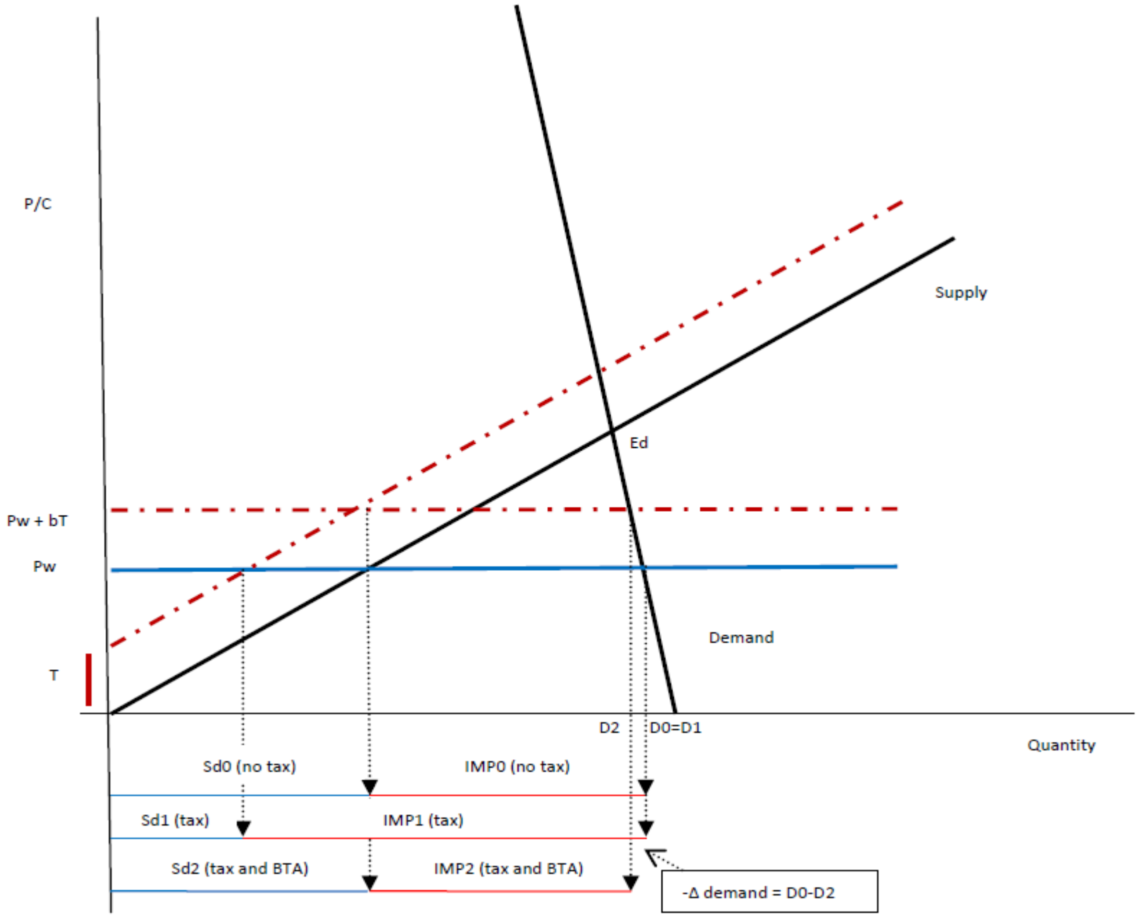
[43] The EU as the biggest single actor in world trade, acting as a customs union coupled with a single internal market for goods and services, can be seen as a 'large country' in general, but its actual size can be different for different goods and services, including different primary commodities and their specific world market. See below for the equilibrium outcomes of a domestic tax coupled with a tariff (BTA) in the case of a 'large country'.

[44] If there are also exports of minerals from the country (here a supposed net importer with no exports), the domestic mining industry will be completely unaffected by the tax/BTA if a compensatory export refund equal to T (or bT in Figure A.1) will be granted for each unit of mineral exported.




These results, however, critically depend on the demand elasticity to price. If demand is very inelastic (lack of resource saving technologies, lack of substitution possibilities) as is often the case with raw mineral resources, the final equilibrium will imply the same equilibrium price but a very limited effect on demand Figure A.2). The higher cost of the mineral resource will be supported by the mineral-using metal industry and absorbed/transmitted (eventually to the final consumer) according to market conditions faced by the metal and metal-using industries (tax incidence).

**Figure A.2. A unilateral tax on extraction when demand is very inelastic to price**




A similar scheme as in Figure A.1/A.2, and similar expected outcomes, applies to a tax with/without BTA applied *on production/supply of a metal* – with a market made by supply from metal producing industry, for example, steel and refined copper, and demand from metal-using manufacturing industries. Even in this case, a critical element for the outcome will be the elasticity of demand to price. In the case of metals, it can be expected that demand will be more elastic to price compared to minerals because material-saving technologies and material-substitution possibilities are more likely to exist in metal-using manufacturing industries. However, the analysis and the estimates reported in this paper suggests that, even in the case of metals, the elasticity of demand to price is low because of, for example, limited material substitution possibilities in many applications (see also the case of an input tax).

*Large economy*

The scheme can be reformulated for a tax + BTA introduced by a 'large trading country', one whose trading is large enough to influence the world market and price. Following the standard theory of tariffs for a large country (Krugman and Obstfeld, 2006), the outcome is different from the 'small economy' case. In Figure A.3, shows the sequence leading to the final equilibrium in the large economy. Compared to a small economy (Figure A1-A2), the world price will pass from Pw0 to a lower-level Pw1 because of the depressing effect of a BTA adopted by the large economy. If the resource tax T and the BTA (=bT) are unchanged, then the new reference domestic price will be Pw1 +bT. This will imply: (i) a final domestic supply Sd3, which is lower than both the level Sd0 with no tax and no BTA and Sd2 (tax + BTA in a small economy, see Figure A.1-A.2); (ii) import at level

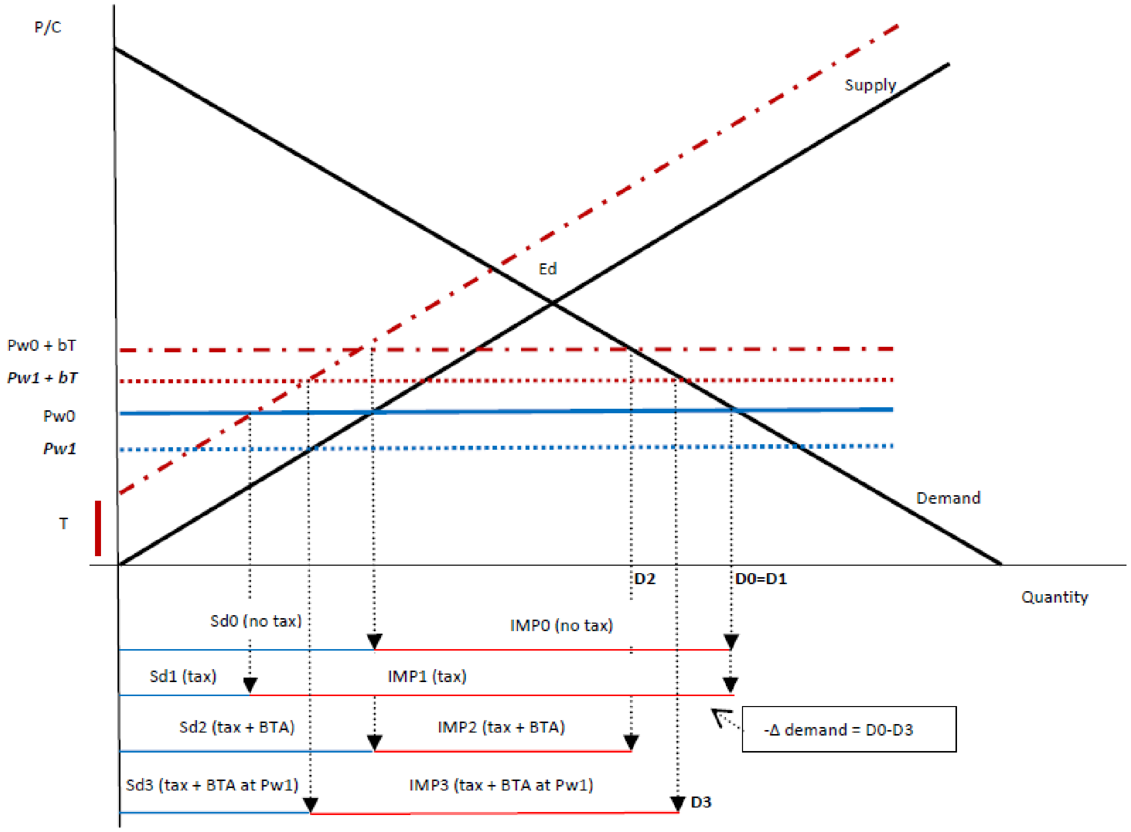
IMP3, which may be lower than IMP0 without tax + BTA, but higher than IMP2, i.e. the case of a small economy; (iii) demand at level D3, which is lower than the demand D0 without tax + BTA but higher than D2 – the demand with tax + BTA in a small economy. In short, when the taxing country applying a tax + BTA is a large economy the prediction by standard models is that domestic supply will be lower, imports will possibly be lower and demand will be lower compared to the case of no taxation. Taxation with BTA from a large country open to international trade (net importer) will then have a negative effect on demand for the resource compared with both non-taxation and taxation without the BTA[45].

The above conclusions critically depend on the responsiveness of the world market and price to the BTA, which in turn can depend on the size of the country in that market and the level of the BTA itself. When the depressing effect of the BTA on the world equilibrium price is very strong, then the country can even see domestic demand D3 increase, instead of decreasing as in Figure A.3, and imports increase as well relative to no tax and no BTA (with domestic supply to decrease even more). This can happen when, with reference to Figure A.3, the depressing effect on the world price is so strong that Pw1, and then Pw1 + bT, decrease to a level lower than Pw0. In this case, the increase in demand, especially in other producing countries through import, will run contrary to the desired effect of the tax on resource extraction and will result in increasing pressures on world resources.

Given the different results between a small and large economy, the question is whether the EU is a small or a large economy in terms of the international trade in the metals/materials considered in this paper. Data presented here suggest that the EU may be a large economy for international trade (import demand) in iron ore, iron and steel; refined copper; phosphate rock and phosphorus but not for copper ores. Thus, with the exception of copper ores, for the adoption of a tax on domestic extraction + BTA, the EU should be seen as a large economy with all the uncertainties on the net global effect we have highlighted above.

**Figure A.3. A unilateral tax on the extraction of a mineral resource (with/without BTA) by a 'large economy' open to international trade (net importer)**

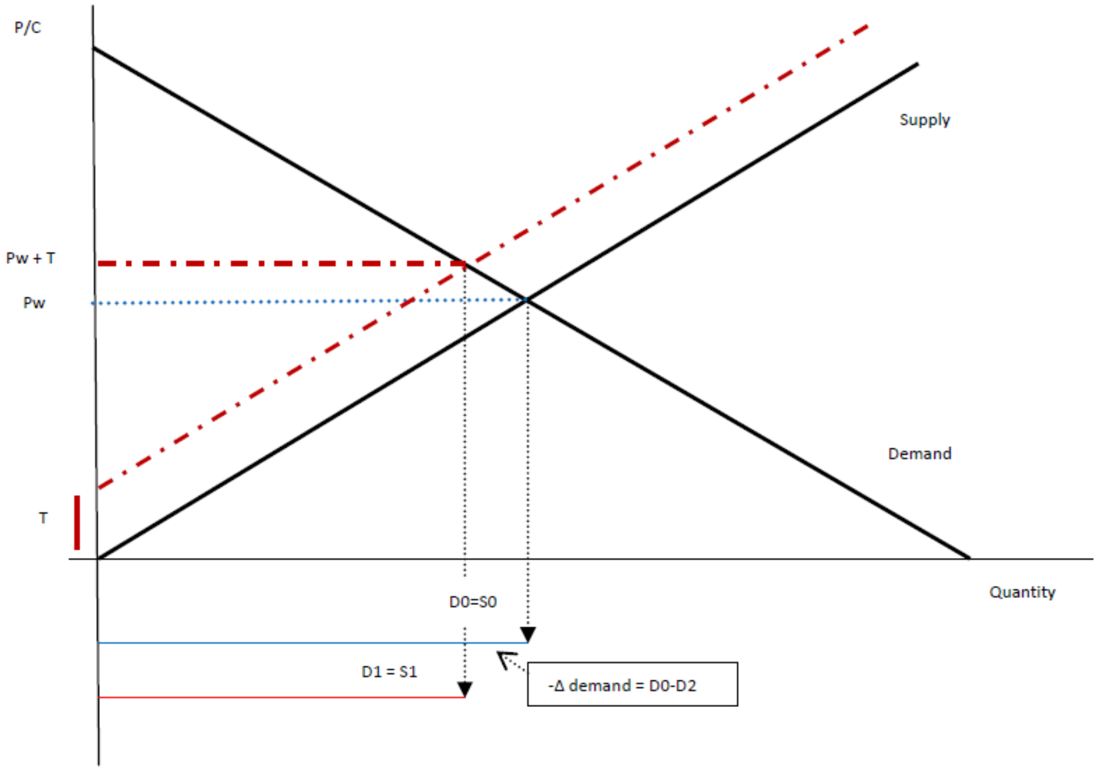
[45] We did not perform a welfare-change analysis of the equilibrium for the large country. Standard conclusions of such an analysis are that, differently from the case of a small country, the large country may even have a net benefit from introducing the tariff (BTA) because of the combined effects of a lower equilibrium price in the world market and the net benefits/costs accruing to consumers, producers, and the State receiving the revenue of the tariff (BTA).




*A global tax on resource extraction*

While we are mainly interested in unilateral resource taxation, it can be interesting to see, with reference to standard market equilibrium schemes, what the effect of a global tax on resource extraction applied multilaterally would be. This possible approach to resource taxation has been proposed by a number of authors including Ekins, Meyer and Schmidt-Bleek (2009), and is presented in Figure A.4. While a unilateral tax by a country open to trade requires consideration of international trade implications in order to see the net effects (Figures A.1-A3), in the case of a global tax the international trade effects can be ignored, at least in theoretical equilibrium analysis, because total world imports equals total world exports. Such trade policy measures as BTAs are therefore not needed. The reference market is the global market and then global supply/demand. The effect of a tax T imposed to total extraction of the resource is to shift the supply function backwards – marginal cost of supply/extraction will be higher and quantity supplied/extracted lower at all price levels. This will, as in standard market equilibrium analysis, bring a new price-quantity equilibrium in which global supply (= global demand) will be lower than without tax (D1 = S1 < D0 = S0), and the price of the resource will be higher than without tax (Pw + T > Pw). The actual decrease in demand will critically depend on the elasticity of global demand (and global supply), as was the case with unilateral taxation (Figure A.2), and then on the techno-economic possibilities of resource saving, substitution and recycling. In the case of demand being completely inelastic (vertical demand function), the effect will only be, for a given supply function, an increase in the price equal to the tax T, which will be possibly transmitted to all manufactured products using the resource, and the quantity of extraction will be (directly) unaffected. In the case demand being of perfectly elastic (horizontal demand function) the tax will not increase the price and instead its effect will be a substantial (direct) reduction of supply/extraction. Therefore, the effect of a global tax on extraction will depend on the technologies of the global manufacturing sectors using the resource as an input. Given that the demand for materials considered is relatively rigid to price, it can be expected that a global resource tax would, at least in the short run, influence the world price more than world extraction[46]. If the major influence is on the price, a full tax incidence analysis (i.e. transfer of the price along the value chain up to consumers) would be needed to see the complete net effects on resource consumption.

**Figure A.4. A multilateral global tax on the extraction of a mineral resource**




***Material input tax***

The effects of a tax applied to a *virgin* metal *as a material input* (material input tax) would need a different scheme of analysis, as presented in Figure A.5 – the case is that of a small economy. In the case of a virgin metal/material taxed at its first use, when the metal enters the manufacturing process for the first time, the tax would correspond to a tax on *metal demand* by industrial users, and not to a tax on the supply of the metal[47]. Given that it is applied on the input of the metal at its first use whatever its origin – non-discrimination between domestic and foreign goods – a BTA is not needed to avoid domestic supply discrimination in this specific virgin metal market, although a more complex BTA could be needed for imported metal-embodying goods. This input tax would correspond to a decrease in the profitability of demanding the virgin metal as an input (a net increase in marginal production cost for each unit of input metal, assuming a given price of the manufactured good, i.e. assuming there is not transfer of the tax to the price of the final good) and then it will reduce the

[46] As usually assumed, in the longer run the higher price can induce innovation that makes demand more elastic to price, and then the tax can be more effective on extraction.
[47] We are referring to a virgin metal that is perfectly distinguishable from a recycled metal.

demand of the metal[48]. This will imply a downward shift of the metal demand function in Figure A.5. The equilibrium price in the concerned metal market will be unaffected and will remain at a level Pw. The domestic supply Sd1 after the tax is expected to be unaffected and will keep its initial level, Sd1=Sd0. Imports will suffer the entire reduction of demand in the domestic market (D1-D0) shifting from IMP0 to IMP1[49].

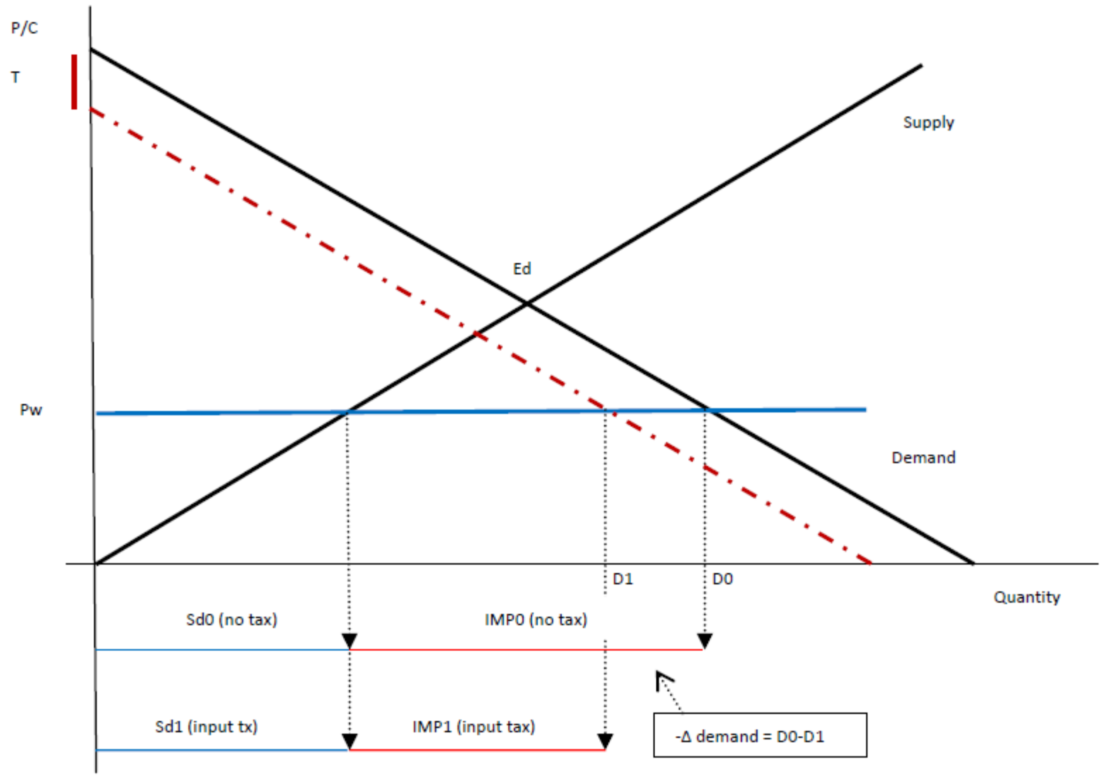
Given that domestic demand of the country will be reduced, it is again relevant whether the country is a small economy (Figure A.5) or a large one. In the latter case, it is possible that outcomes similar to those of the extraction tax with BTA (Figure A.3) – a depressive effect on the world price, possibly bringing lower or higher demand, will prevail together with the associated uncertainty on the net (global) effect of the tax.

Therefore, from a resource policy perspective, an input material tax for a specific metal/material is expected to directly affect (decrease) the demand for the metal/material itself, with no need for a specific BTA and, in principle, no discrimination/disadvantage for the domestic metal industry. While simple in theory, the problem of this taxation approach will be that, in order to be really non-discriminatory, the input tax should also be applied to the metal content of intermediate and final *imported* goods – those produced domestically are already subject to the tax at the first use of the metal as an input. This would require a very complex and information-demanding system of BTAs and export refunds on the metal content of all imported and exported goods[50]. If the country is a large one, this complex BTA mechanism might in principle affect the world trade for a number of products of which the country is an importer.

A mechanism of taxation on inputs is exemplified by the case of phosphorus[51].

**Figure A.5. A unilateral tax on a metal used as an input (input material tax) in a 'small' economy open to international trade (net importer)**

[48] We are excluding the fact that the input tax imposed on metal users will be transferred back to metal producers through contracts and/or that metal producers will accept bearing the tax burden to keep demand of their output at the same level as before the tax, which otherwise would *de facto* bring back a tax on supply as in Figure A.1/A.3.
[49] The fact that all the decrease in demand will be reflected in a decrease in imports and not in domestic supply is an assumption enshrined in standard trade policy models, given their aim. Actually, domestic supplies enjoy a producer surplus – the difference between price and marginal production cost – from zero to Sd0=Sd1 whereas all imports are assumed to face Pw, which would give domestic supply a possible advantage. However, it cannot be excluded that in the real world both domestic supply and imports will share, equally or unequally, the decreasing demand, and are likely to react by changing their price strategy.
[50] The effects of an excise tax on intermediate inputs in an open economy with reference to natural resources (based on the resource content of final goods) are presented in Poterba and Rotemberg (1995).
[51] Other interesting examples can be found in the packaging policy of some countries, for example, the Italian compliance scheme CONAI. In the CONAI system, which is composed of material-specific consortia, a fee is raised at the first use of all packaging materials in the domestic market. The fee is collected at the level of producers and importers of empty packaging put on the market for the first time, thus being an output tax, but also by importers of packed merchandise, thus being an input tax. Exported packaging, in whatever form, is exempted from the fee (CONAI, 2014).




***Substitution***

The decreasing demand for the metal in a scheme with a material input tax (Figure A.5) but also if applied to a supply tax in the metal market (Figure A.1/A.3) will depend: (i) (inversely) on the possibility of transferring the tax (an additional production cost) to the manufactured product price, which we have excluded for simplicity, and (ii) on demand elasticity to price, that is the slope of the demand curve of industrial users. This elasticity can depend, *inter alia*, on the techno-economic possibilities of substitution.

A very simple *economic* scheme of material substitution is shown in Figure A.6 for two metals in the same manufacturing application. We assume that the two metals, for example, aluminium and copper, are technically perfect substitutes in a specific industrial application, thus allowing for a purely economic decision based on relative costs/prices. We further assume that the application is such that it could represent a significant market, for example, cables, in which manufactures' demand is large enough to affect a significant part of the total supply function of the two metals for the application. In this case, the manufacturers' choice of the metal mix is not made at given (exogenous) prices of the two metals and, given the marginal cost function of the two metals in competitive markets, relative demand of the two metals can define the equilibrium market price of both metals[52].

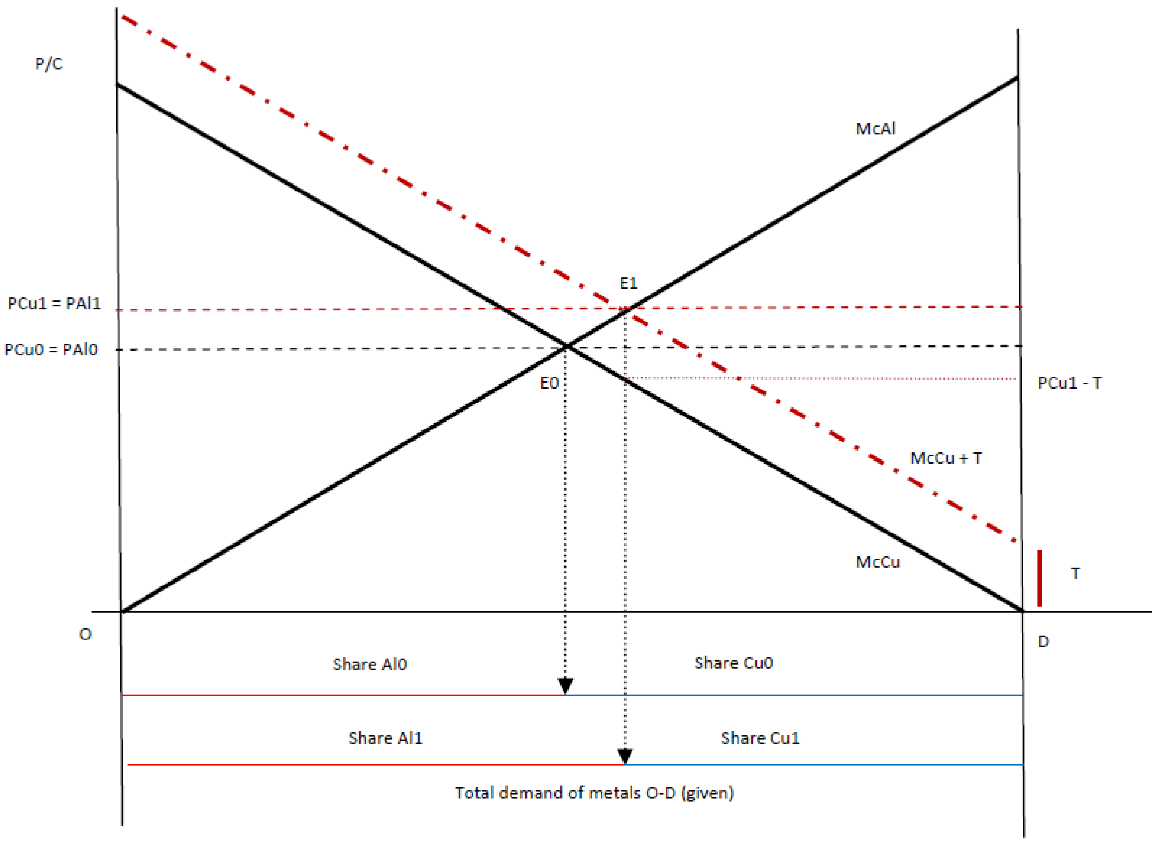
[52] In a standard optimal decision of input demand by a firm when inputs are perfect substitutes, the production function is a linear function of the total amount of inputs with a unit marginal productivity of all inputs (Varian, 2014). In this company-level decision, the prices of the inputs are given and are not influenced by the input demand decision – different from the input(s) market equilibrium scheme considered here.

Total demand for metals in the application is the length O–D on the horizontal axis and it is given (exogenous). It can be satisfied entirely by Al at an increasing marginal cost along the supply curve McAL (from left to right along O–D) or entirely by Cu at an increasing marginal cost along the supply curve McCu (from right to left along D–O). The economically optimal mix of the two metals, given that they are technically perfect substitutes, will be defined only by the relative price – a marginal cost in a competitive market – of the two metals[53]. The equilibrium mix will be defined by the point E0 at which the price, equal to the marginal cost of supply, to the user is the same for the two metals[54]. Given the total metal demand O–D, at this equilibrium point the share of Al will be Al0 and the share of copper will be Cu0.

Now suppose that a tax T is imposed on each unit of copper produced/supplied, and not on aluminium. The marginal cost curve of copper (McCu) will shift backwards by an amount proportional to T (McCu+T) and its cost/price for the using industry will increase correspondingly. This will cause a new optimal mix of the two metals (defined by E1) for a given total demand in the application, with an increase of the share of aluminium (now Al1>Al0) and a decrease of the share of copper (now Cu1<Cu0). The new equilibrium price of both metals (in the market for the application) will be higher for the using manufacturing industry (PCu1=PAl1 > PCu0=PAl0) than before the tax on copper, and its total production costs will increase, also depending on the relative slope of the supply curves for aluminium and copper. This increased cost with substitution will of course be lower than the increasing costs eventually incurred with a tax on copper and no substitution – keeping the metal mix at E0). Even with higher market price in the market for the application for both metals, aluminium producers will actually enjoy a higher price (PAl1>PAl0) with an increasing quantity sold, whereas copper producers will enjoy a price without tax (PCu1 –T) which is lower than PCu0, and will lose sales[55].

**Figure A.6. Substitution between two technically perfect substitute materials with a tax on one material (given total demand in an industrial application)**

[53] We could represent imperfect substitutability through assigning an extra cost factor to one of the metals, which, if the extra cost factor is fixed for all quantities, would shift the cost/supply function of the inputs without changes in the results from Figure A.6.
[54] Note that beyond the point E0 (when reading from left to right), the marginal cost of using aluminium in the application will be higher than the marginal cost of using copper, and then E0 will define the maximum amount of aluminium that will be used. Symmetrically, beyond the point E0 (when reading from right to left), the marginal cost of using copper in the application will be higher than the marginal cost of using aluminium, and then E0 will also define the maximum amount of copper that will be used.
[55] We do not develop a full ‘welfare change’ analysis here.




***Recycling/secondary materials***

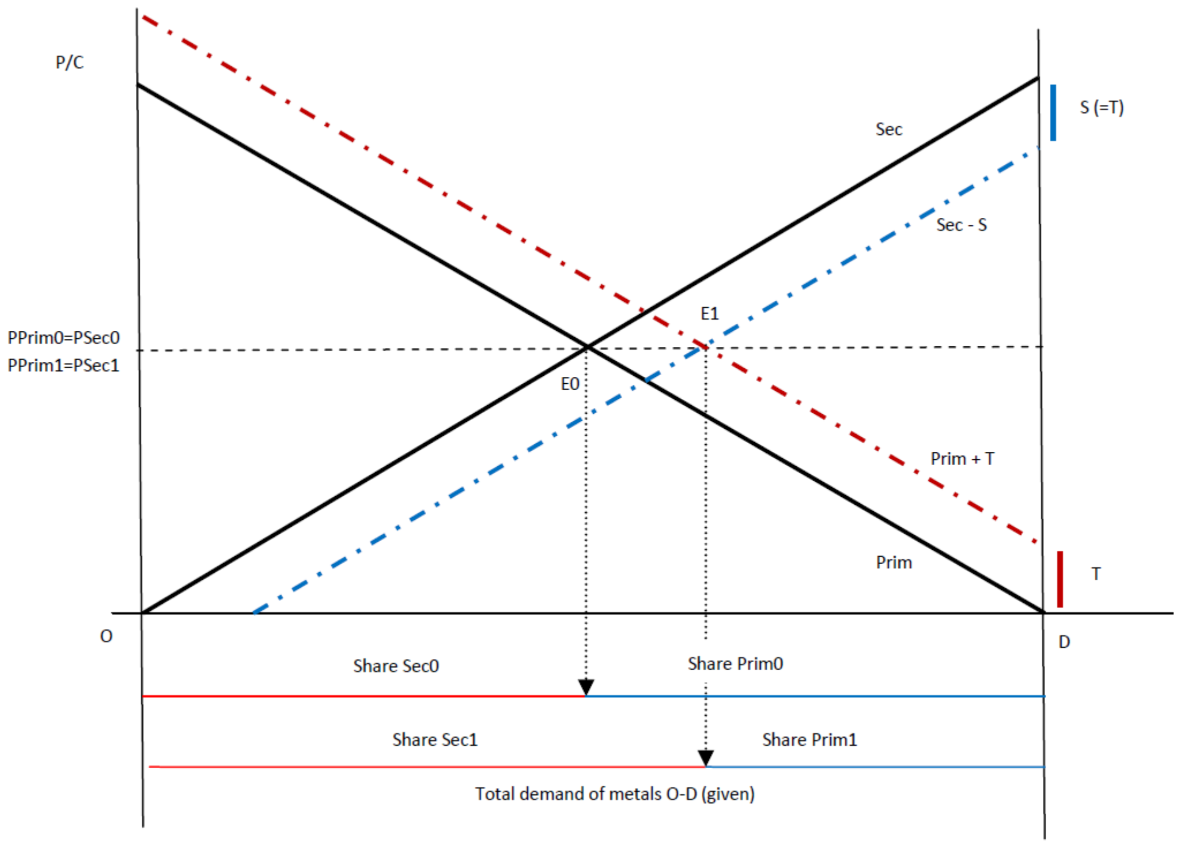
The scheme in Figure A.6 can be used to also sketch the possible consequences of a tax on a virgin metal/material in terms of substitution by a corresponding secondary (recycled) metal/material. When adopting the simplifying assumption that the primary and secondary metal are perfect substitutes, a tax T on the virgin metal will logically bring at the same results as the scheme for material substitution in Figure A.6: for given total demand of the metal, a tax on the virgin material will decrease its market share, the share of secondary material will increase (more demand of recycling), and the price/cost of the two will increase in the application market with, however, the equilibrium price of the virgin material, after deducting the tax T, lower than before the tax.

An interesting variant could be a policy that, in the same setting as Figure A.6 when applied to substitution by secondary/recycled materials, uses (earmarks) the revenue of the tax raised on each unit of the virgin metal/material (T) to subsidise (S=T) each unit of the corresponding secondary material used in the same application. The results are shown in Figure A.7.

A tax T will shift the marginal cost curve of the virgin materials (from Prim to Prim +T) backwards, thus putting the virgin material at a relative disadvantage for substitution (which alone would occur at the same equilibrium of substitution depicted in Figure A.6). The subsidy S (=T and financed by T) applied to each unit of the secondary material will shift the cost (supply) curve of secondary material forward (from Sec to Sec-S). This joint shift of the two supply curves, for a given total demand, will bring to a new equilibrium E1 in which: (i) the share of the secondary material will increase significantly, and more than in the case of a virgin material tax only (compare to Figure A.6); (ii) the equilibrium price of both virgin and secondary material will be unchanged with respect to the initial level before tax T plus recycling subsidy S (equilibrium prices in 1 are the same as prices in 0).

The results, therefore, will be that the metal-using manufacturing industry will not have additional costs from using a different combination of virgin and secondary metal/material, different from the case of a tax on virgin material alone, and the share of secondary recycled material will be much higher than in the case of a tax on virgin material only (compare to the substitution scheme in Figure A.6). All these results are, of course, only valid within the simplified assumption of the scheme.

**Figure A.7. Substitution of a taxed virgin material by a secondary material, with the tax revenue earmarked to subsidise recycling (given total demand)**




### *Final consumption tax*

The case of a unilateral tax on the consumption of a final good - a durable consumer good, for example - that is intensive of certain metals/materials is not too different from the case of a tax raised on a material input – demand tax at first use – as represented in Figure A.5[56]. For a small economy able to import the final good from the world market, the reference domestic price is the world price Pw. If the tax is on the final good bought by consumer, it will be paid by the consumer and is

[56] Even in this case, we assume that the tax is borne by the consumer of the final good and is not absorbed through discount policies by either the seller (retailers) or the manufacturer. In other words the tax is not transferred back along the value chain of the final product.

independent of the origin of the product, domestic or imported. A specific BTA on the product is not necessary.

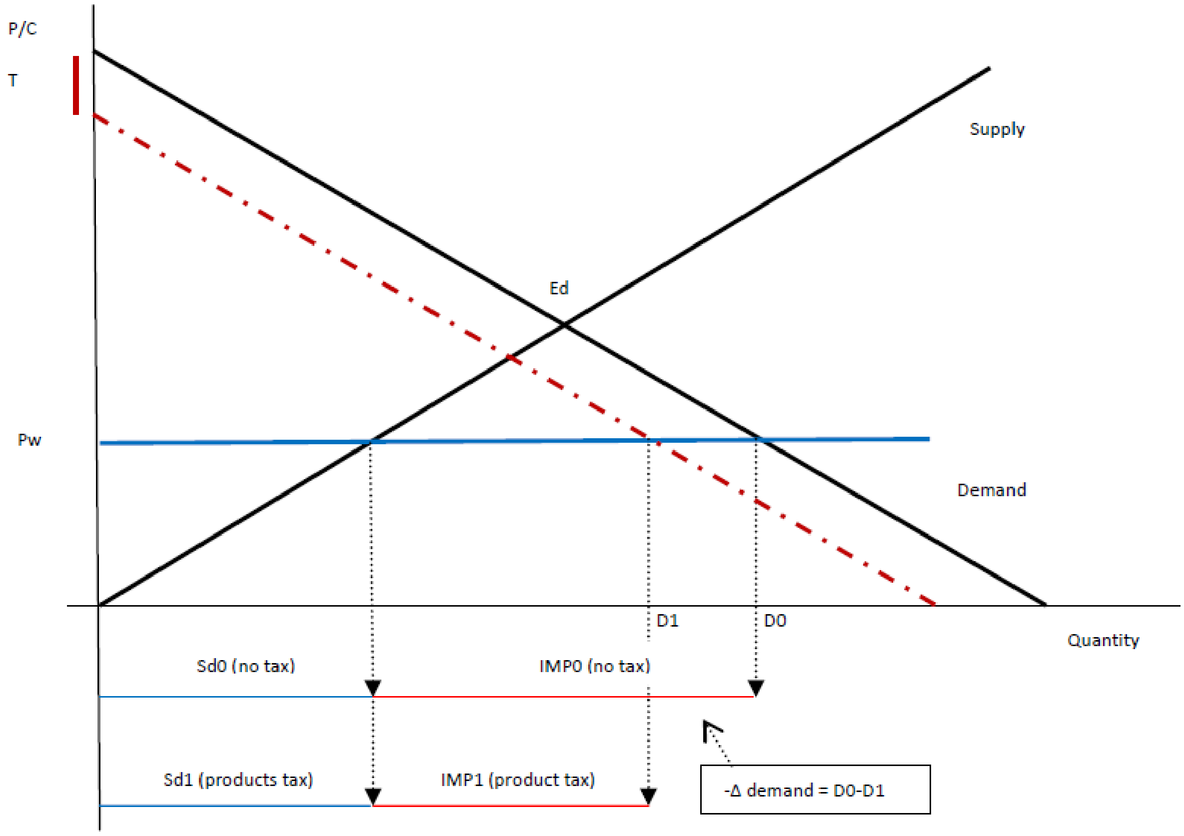
The effects are shown in Figure A.8. Whatever the tax base, such as the measured material(s) content of the final good, the effect of a tax is to proportionally shift the demand of the product downwards – the net benefit of consuming the product is reduced for all the price levels on the vertical axis.While the price of the good will not change (Pw), demand for the product will be reduced from D0 to D1. Given the elasticity of demand, the reduction of the demand of metals/materials will be proportional to the tax and then, if the tax is somewhat proportional to material content, proportional to the resource quantity embodied in the final product[57]. In short, the effect would be similar to that of an indirect tax on a consumer good in standard microeconomic analysis (Varian, 2014).

Of course, the reduction in demand for the taxed product does not necessarily correspond to a net total demand decrease by consumers. Consumers can simply re-allocate demand to non-taxed products that can be a good substitute, as suggested by standard models of consumer demand, with possibly complex effects on quantities of different goods consumed – income effects, price effects, substitution effects, etc. (Varian, 2014)[58]. Substitution effects within consumer choice will depend on the features of the taxed good (normal, luxury, etc.) and then the effect of the tax, given its level, will depend on the elasticity of demand to the price of the good. If demand is rigid, the effect on the quantity demanded will be small and the effect on price will be large, and *vice versa* in the case of elastic demand. These complex possibilities of substitution of the final good within consumer choice can also make the net effects on resources uncertain because substitute goods could be intensive of non-taxed resources or have higher environmental impacts, for example, air emissions. To avoid adverse net effects on resources and the environment, a multi-resource tax or a resource-intensive product tax could be envisaged. However, for the market equilibrium of a specific good any taxation approach would work as in Figure A.8 with just the tax base being different.

**Figure A.8. A unilateral tax on a final consumption good, based on the material(s) embodied in the good (small economy open to international trade, net importer of the product)**

[57] Even in this case we assume, following trade policy models, that all the reduction in demand would be at the expenses of imports and not of domestic supply, but this might not be the case in the real world.

[58] If total demand is given, there are just two products, the taxed one and the non-taxed one, and they are perfect substitutes, the reallocation could work as in Figure A.6, with an increase in the price at which the consumer could procure the two consumer products and a shift in demand towards the non-taxed product in a zero-sum game. However, if there is an increase in the price of the two products, there could also be income effects, as in standard demand theory, with additional effects on total consumer demand.


P/C
T
Supply
Ed
Pw
Demand
D1
D0
Quantity
Sd0 (no tax)
IMP0 (no tax)
Sd1 (products tax)
IMP1 (product tax)
-Δ demand = D0-D1