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## Summary

Increasing material use efficiency is important to mitigate future supply risks and minimize environmental impacts associated with the production of the materials. The policy mix presented in this paper aims to reduce the use of virgin metals in the EU by 80% by 2050. We used a heuristic framework and a systems perspective for designing the policy mix that combines primary instruments (aimed to achieve the 80% reduction target – e.g. a materials tax, technical regulations and removal of environmentally harmful subsidies) and supportive instruments (aimed to reduce barriers to implementing the primary instruments and to contribute towards the policy objectives – e.g. research & development support, and advanced recycling centers). Furthermore, instruments were designed so as to increase political feasibility: e.g. taxes were gradually increased as part of a green fiscal reform, and border-tax adjustments were introduced to reduce impacts on competitiveness. However, even in such a policy mix design ongoing ex-ante assessments indicate that the policy mix will be politically difficult to implement – and also fall short of achieving the 80% reduction target. Nonetheless, we suggest combining primary and supportive instruments into coherent and dynamic policy mixes as a promising step towards system reconfigurations for sustainability.

**Keywords:** Policy Mix, Policy Development, Resource Efficiency, Material Efficiency, Recycling, European Union, Sensitivity Model

**JEL Classification:** L72, Q32

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# A systemic approach to the development of a policy mix for material resource efficiency

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**Abstract:**

Increasing material use efficiency is important to mitigate future supply risks and minimize environmental impacts associated with the production of the materials. The policy mix presented in this paper aims to reduce the use of virgin metals in the EU by 80% by 2050.

We used a heuristic framework and a systems perspective for designing the policy mix that combines primary instruments (aimed to achieve the 80% reduction target – e.g. a materials tax, technical regulations and removal of environmentally harmful subsidies) and supportive instruments (aimed to reduce barriers to implementing the primary instruments and to contribute towards the policy objectives – e.g. research & development support, and advanced recycling centers).

Furthermore, instruments were designed so as to increase political feasibility: e.g. taxes were gradually increased as part of a green fiscal reform, and border-tax adjustments were introduced to reduce impacts on competitiveness. However, even in such a policy mix design ongoing ex-ante assessments indicate that the policy mix will be politically difficult to implement – and also fall short of achieving the 80% reduction target. Nonetheless, we suggest combining primary and supportive instruments into coherent and dynamic policy mixes as a promising step towards system reconfigurations for sustainability.

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## 1. Introduction

Human consumption of renewable and non-renewable material resources is skyrocketing. Global resource consumption has seen marked increases in the last century, in particular since the 1950s [1,2,3]. In transforming these materials into products, food, energy functions for mobility and housing and the necessary infrastructure [4], also significant environmental impacts are generated: a large share of ecosystems becomes ever more degraded [5], some 50 $GtCO_2e$ are emitted annually [6], and the global ecological footprint of human activities amounted to more than 1.4 planet Earths in 2005 [7]. Global megatrends risk exacerbating the situation in the future and further challenge the likelihood and feasibility of transitioning to more sustainable resource use pathways. Rising global population and affluence levels, ever more widespread adoption of westernized lifestyles and production and consumption patterns will contribute to future increases in resource consumption, which is expected to reach approximately 140 billion tons of minerals, ores, fossil energy carriers and biomass by 2050 [8], more than doubling from the 68 billion tons reported for 2009 [1]. Such resource use and associated environmental impacts contribute to (further) transgressing existing planetary boundaries [9]. Human activities are expected to require two planet Earths around 2030 [10] and fossil-fuel dominated energy use will increase by almost 80% by 2050 [11].

Hence, increasing the efficiency in the use of material resources is important for several reasons. One is to use materials more efficient in order to generate as much economic value and/or well-being and serve as many functions as possible with a given resource base. Furthermore, the use of resources and in particular the production of bulk materials (steel, aluminium, concrete, etc.) is responsible for a significant share of the energy demand and green house gas emissions of human society. In addition, increasing resource use efficiency can counteract risks related to future supply of certain materials, because the resources are likely to be scarce in the mid-term (relevant for, e.g., silver), or because the mineral reserves and/or mines are located at very few places in the world (relevant for, e.g., several rare earth metals [12]).

Hence, increasing efficiency of material use is important to steward our resource base and enable present and future generations to benefit from using resources sustainably, thus increasing the resilience of social-ecological systems and achieving a more sustainable economy in the long term.

However, policy-making for resource efficiency is a complex and large-scale challenge. A single material is typically used in many different applications and sectors. Economic interlocking of streams of resources, semi-finished and finished goods a makes resource policy a policy field involving a multitude of interdependent actors in value chains that cross national boundaries and on markets that are often global. Taking into account the specific conditions of each application and each actor is hardly possible. And yet, failing to do so increases the risk that policy interventions shift the use of resources to other applications or regions of the world, rather than increasing resource efficiency. Furthermore, efficiency gains obtained from improving resource use efficiency may trigger greater consumption of the same good/service or of other goods and services, eventually backfiring and causing rebound effects [13]. These complexities, the many functions that material resources serve, and the multitude of involved actors in multi-actor-systems call for a more systemic approach to resource policy making. Such an approach would need to allow policy makers to account for the most important aspects and causal relations between relevant trends and drivers and their effects when designing policies. Furthermore, such an approach requires a very broad systems perspective in order to capture as much as possible the system's complexities and to allow for evaluation and – if found useful – dissemination of the chosen approach.

The project 'DYNAmic policy MIXes for absolute decoupling of environmental impacts of EU resource use from economic growth' (DYNAMIX, FP7 project, www.dynamix-project.eu) has tested a systematic approach in developing a policy mix for reducing consumption of metals and other materials in the EU by 2050. The procedure for developing the policy mix has been reflected upon and revised as part of the DYNAMIX project. This paper describes this approach and uses the policy mix for material-resource efficiency as an example to illustrate the procedure.

This paper outlines the multi-step development process and details the policy mix designed. For this purpose, we will first describe the development process and the heuristic framework used (Section 2) and then detail the policy mix following the different steps of the heuristic framework (Section 3). Then we will discuss (Section 4) both the policy mix and the conceptual approach used.

## 2. Materials and Methods

### *2.1 Heuristic framework for designing policy mixes*

The DYNAMIX project aims to identify and assess dynamic and robust policy mixes to shift the EU onto a pathway to absolute decoupling of long-term economic growth from resource use and environmental impacts and to reduce resource use to a sustainable level.

Three DYNAMIX policy mixes were developed (one of which is the metals and materials policy mix presented here) through a systematic systems approach elaborated based on the heuristic framework adapted from Givoni et al. [14]. This encompasses the following stages (see Figure 1 below):

(1) Defining longer-term objectives and setting of short- to medium-term, more concrete targets for the respective policy areas;
(2) Elaborating a theoretical causal model for problem solving in the policy areas (what is the problem situation? What are contributing drivers? What does impede changes?);
(3) Selecting, based on heuristics and expert guessing, promising instruments from known potentially relevant policy instruments contributing to problem solving to form an initial policy mix;
(4) Undertaking ex-ante assessments (literature based qualitative assessments, participatory scenario building and quantitative computer model simulations) of the initial policy mix as to its potential effectiveness and impacts. This usually entails comprehensive scientific analyses, which then enable substantiated decision-making as to whether or not to include the instrument analysed into the mix;
(5) Adding, if the initial mix was found sub-optimal against the set objectives and targets, further instruments to the mix or revising existing instruments and re-running the assessment (repetition of steps (3) and (4)) to finalise the policy mix;
(6) Preparing the final policy mix for implementation, enforcement and monitoring.

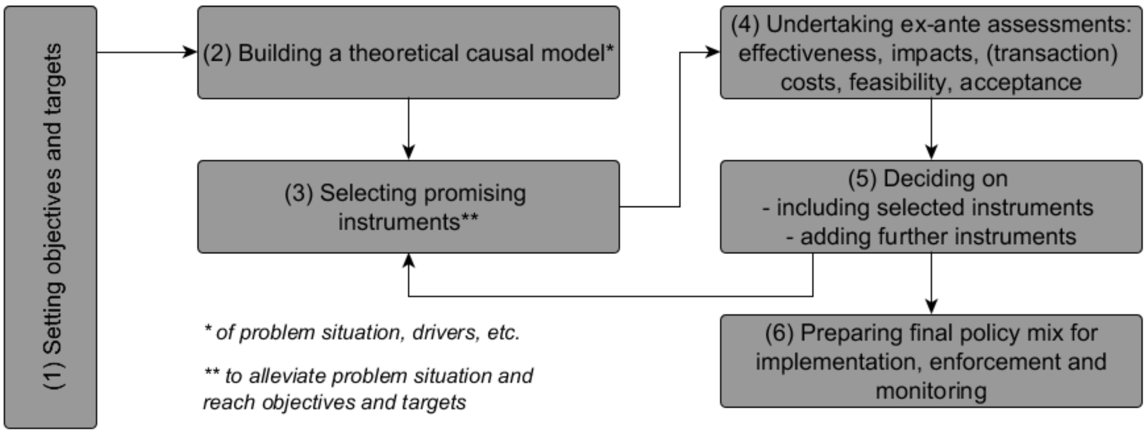



**Figure 1.** Heuristic framework for policy mixing; Source: adapted from [14].

The final stage of the framework was not undertaken as the DYNAMIX project aims to give recommendations to European and national policy makers, but not to prepare a mix for implementation or enforcement. Furthermore, this paper only deals with Steps (1) to (3).

A policy mix goes beyond combining loosely or rather unconnected policy instruments. In fact, in a policy mix long-term qualitative objectives and short- to mid-term quantitative targets are linked to an instrument set applied in a time-dynamic sequential process approach to achieve the objectives and targets. Therefore, compiling a policy mix requires

- a forward-looking roadmapping, i.e. relating different policy instruments to each other in a time sequence that helps optimizing synergetic effects and minimizing unintended negative side-effects
- consideration of political processes in multi-actor networks and polycentric governance systems in order to be able to monitor processes and adapt the mix in feedback loops over time.

Thus, the concept of policy mixes appears to clash with political practices and experience, where policy formulation often entails so-called policy layering, i.e. stacking new instruments or objectives on-top of existing ones without any overarching design [15]. Resulting from political needs, such as existing alliances, election-based tactics or lacking time or knowledge, policy layering increases the risk of unplanned mixes with contradicting objectives and measures and hence trade-offs in effectiveness.

Designing, implementing and evaluating policy mixes is much more difficult than individual instruments loosely bundled. Political realities as well as the dynamics and path dependencies of legislative periods run counter to a strategic and more long-term implementation procedure of policy mixes. Therefore, compiling a policy mix needs to consider political process in multi-actor polycentric governance systems to identify and exploit opportunities for long-term, adaptive policy formulation.

In this context, designing a policy mix needs to ensure a good fit between instruments and targets within a single level of policy (horizontal mixing) as well as with institutional framework conditions (i.e. various policy fields and governments active in these fields = vertical mixing) [15]. This encompasses the need to consider both consistency and coherence of the instruments sequentially linked in a policy mix. While consistency in a more narrow sense denotes the absence of conflicts and contradictions, coherence refers to ensuring synergetic effects and positive interactions between instruments (denoted as strong consistency by Rogge and Reichhard [16]) as well as between different policy and administrative levels [15, 16].

Consistency and coherence can be fostered by combining primary with supportive instruments. Primary instruments mainly serve to achieve the/a set objective and should be as little controversial as possible; supportive instruments serve to minimize or mitigate unintended negative side-effects of primary measures and hence to increase their acceptability and feasibility [14, 16].

*2.2 The process to designing the metals and materials policy mix*

A target for reduced use of virgin metals in the EU was defined at the outset of the DYNAMIX project [17]. The target was quantified in terms of raw materials consumption (RMC), which is essentially the quantity of ore extracted to produce the metals.

A handful representatives from different project partners, countries and scientific disciplines was given the task to develop a policy mix aiming at supporting, if not achieving, this target. This author team added further objectives specifically to this policy mix, widening its scope so as to avoid that the policy mix mainly causes burden shifting to other regions or materials.

We used European statistics to identfy the metals that dominate the total use of virgin metals. A literature review and background knowledge were used for identifying the drivers of the use of these key metals and the barriers to more efficient use of both the metals and other materials.

Part of the background knowledge was synthesized through the use of the Sensitivity Model. This is a computer supported management and planning tool developed to assess and represent complex systems by a) capturing and visualizing relevant areas and parts influencing a system, b) making interrelations and interdependencies transparent, c) identifying the relevant levers and critical elements to steer a system into the desired direction and d) allowing for scenario simulation [18]. The team used the first three elements for developing the policy mix. Scenario simulation could in principle be used for assessing a policy mix; however, the simulation in the Sensitivity Model is highly dependent on a few critical and typically rough estimates and we have selected more advanced modeling tools available in the project consortium (macro-economic models, life cycle assessment, etc.) over the use of the sensitivity model for the assessment of the policy mix. Hence, we applied only the following steps of the Sensitivity-Model procedure:

1. Identifying 20 to 40 of the most important variables (GDP, resource use, environmental pollution, etc.) in the policy field.

2. Finding consensus on qualitative estimates of the interlinkages and causal relations between these variables.
3. Analyzing the systemic role of each variable to identify the most sensitive (i.e., strongly affected by policy instruments or other variables), active (i.e., affect other variables strongly), or critical (i.e., strongly affected by and strongly affect other variables).
4. Creating a so-called Effect System to illustrate the interdependencies among parameters.

Based on this procedure, the team combined a preliminary set of policy instruments promising to tackle the identified drivers and barriers into a dynamic policy mix [19]. This policy mix was presented to the rest of the DYNAMIX researchers during project meetings and to a wider audience during stakeholder workshops (DYNAMIX policy platforms) and then revised based on feedback obtained to form a more coherent policy mix on efficient use of material resources.

## 3. Results

### *3.1. Objectives and targets for the policy mix*

The DYNAMIX project has the overall objective of absolute decoupling and sustainability. The broad concept of sustainability has been operationalized for environmental sustainability by setting five key targets for the year 2050 [17]:

- Consumption of virgin metals: to be reduced by 80%, measured as RMC, compared to 2010 levels in the EU. This target represents the scarcity of metals and environmental impacts caused by extraction, refinement, processing and disposal of metals.
- Greenhouse gas (GHG) emissions: to be limited to 2 tons of $CO_2$ equivalent per capita per year. This is to be measured as a footprint to reflect both emissions generated within the EU and those embedded in imported products. This target represents climate change impacts of greenhouse gas emissions through energy use as well as agricultural and industrial processes.
- Consumption of arable land: to reach zero net demand of non-EU arable land. This target represents, as a rough approximation, the impacts of biomass production on soil quality, water quality and biodiversity.
- Nutrients input: reducing nitrogen and phosphorus surpluses in the EU to levels that can be achieved by the best available techniques. This target represents the impacts of agricultural production on marine and freshwater quality as well as soil quality.
- Freshwater use: no region should experience water stress.

The target on metals is based on previous research [20, 8] and was set to help reduce resource consumption in industrialised countries by 60-80% to reach a sustainable level, at least for abiotic resources like metal ores, non-metallic minerals and fossil energy carriers. The use of fossil energy carriers and non-metallic minerals (e.g. phosphorous) are covered by other targets set out in the DYNAMIX project, because they are strongly linked to GHG emissions and the use of nutrients. For this reason, the target for reduced use of abiotic resources focuses on metals. This was the primary target of our policy mix. Two other policy mixes were developed within the DYNAMIX project to respond to the other four targets: a policy mix on land use and an overarching policy mix.

The use of virgin metals can be reduced through a gradual increase in material use efficiency, in metals recycling, and through substitution by other materials. An increase in material efficiency here means a reduction in the quantity of material required to provide a specific function or produce a monetary unit of economic output.

Although the geographical scope of the policy is the EU, the policy needs to also account for impacts beyond its boundaries. A policy that simply shifts material resource use or environmental impacts from the EU to other parts of the world does not address global environmental justice nor realities of complex international value chains. To reach a sustainable future, the global recycling rate is more relevant than the recycling that takes place within the EU. The share of recycled material used in the EU has only limited relevance on a global scale and to stay within planetary boundaries. Metals are traded globally and recycled metals are a good substitute for virgin metals. If EU policy increases the use of recycled metals in the EU, this will likely shift the use of virgin metals to other countries rather than increase the global recycling rate. To increase the global recycling rate, it seems more efficient to increase the supply of recyclable material from the EU through improvements in, for example, the sorting and collection of waste.

Metals compete with many other materials in important applications: with concrete and wood in constructions, with paper and glass in packaging, with polymers in packaging and in components in machinery, and with textiles in furniture. However, shifting to the use of other materials sometimes is detrimental for the environment, the economy or other societal goals. A reduced use of reinforcement (steel) bars in concrete buildings is, for example, likely to result in an increase in the use of concrete large enough to increase total GHG emissions. To avoid burden-shifting to other material resources, the scope of the policy needs to be expanded to include not just metals but also the competing materials. Therefore, the objectives of the policy mix are to:

- Increase material efficiency for metals and all competing materials
- Increase the global recycling rate of these materials
- Substitute metals by other materials, where this is beneficial for the environment and well-being

*3.2. A causal theory for problem solving*

*3.2.1 Drivers for metal use*

Consumption of virgin metals in the EU is dominated by iron, copper and gold (see Figure 2). Reducing virgin metals use by 80% requires measures to significantly reduce the use of at least these three metals.

Metals are used in all sectors of the economy; hence, metal use has a diversity of drivers. Key drivers causing unsustainable resource use in general were identified at the early stages of the DYNAMIX project [21]: the identified materials-related drivers included, e.g., proliferation of consumption-based lifestyles linked to rising income and emerging social norms of material aspirations or resource prices, which are both increasingly volatile and (still) mostly ignorant of the true external costs of the resources' use. We found the drivers to affect each other in a complex web of causal relationships much rather than in simple causal chains. The Sensitivity Model (see Section 2) allows us to analyse a simplified version of this web, where we selected only 29 variables out of the almost infinite number of variables in the real economy. When we illustrate the web, we can also select to present only the strongest causal relationships between these variables: the arrows in the Effect System (Figure 3). Note that besides these strong relationships, there are many more, weaker relationships between the variables in the Sensitivity Model.

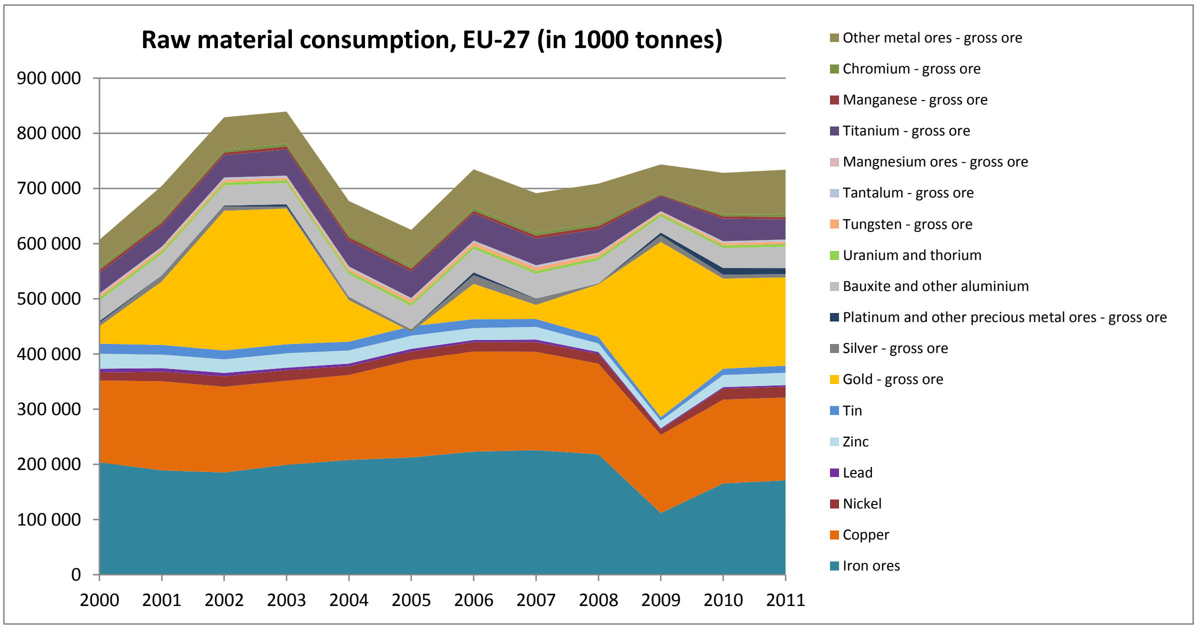



**Figure 2.** Metal use in the EU-27 ([19] based on [22].

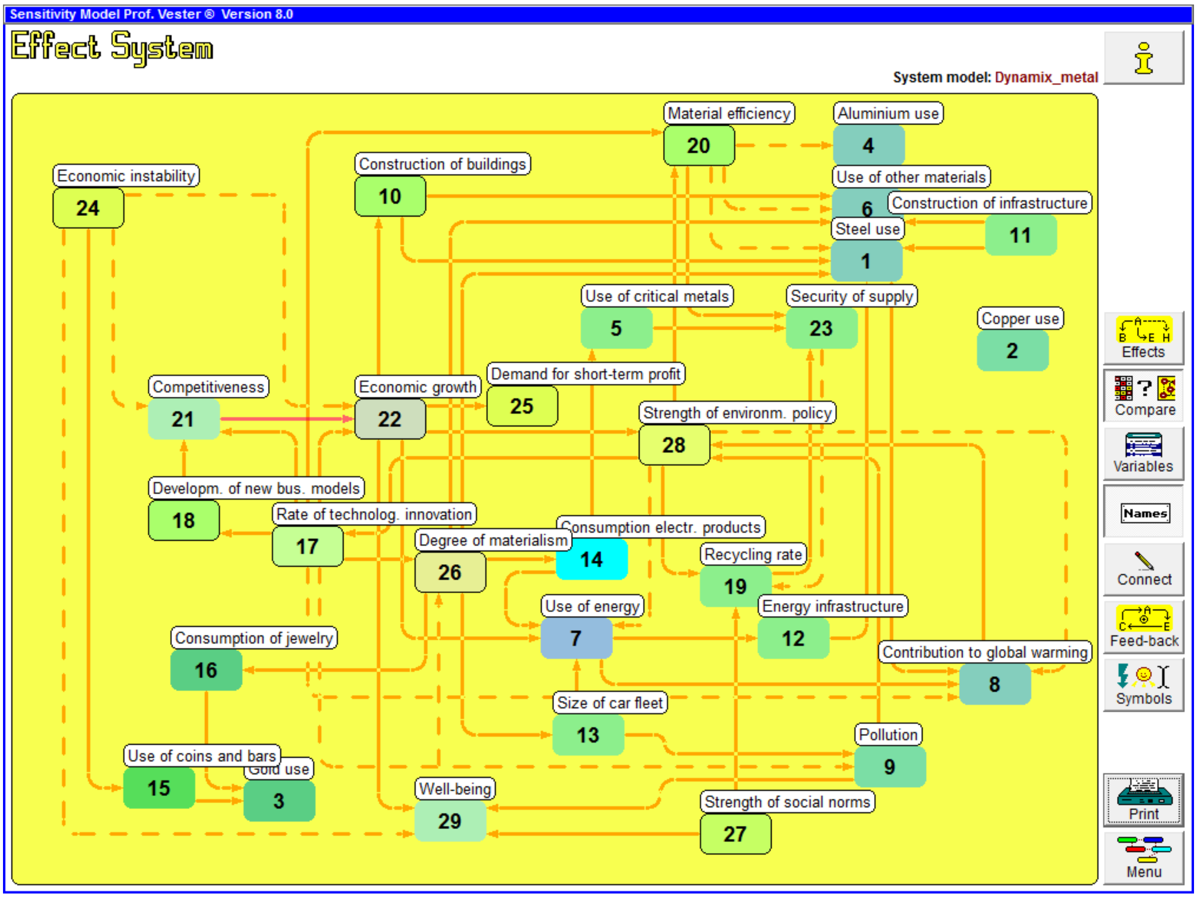



**Figure 3.** The Effect System from the Sensitivity Model illustrates a few of the most important causal relationships between the variables in the system affected by the metals policy mix ([19]). The 29 variables we selected are given a number as well as a short name in the figure. Solid arrows illustrate a strong positive causality, where an increase in one variable causes an increase in the other. Dotted arrows illustrate a strong negative causality, where an increase in one variable causes a reduction in the other.

Iron is mainly used for the production of steel. Steel is to a large extent used for the construction and maintenance of buildings and infrastructure (56% globally, 35% in the EU), but also in machines, vehicles and many other products [23, 24]. This means that expansion and replacement of infrastructure, housing and commercial buildings are important drivers for steel use (Variable 1 in Figure 3). The growth of transport equipment, machinery and appliances is also a significant driver. All of these are closely linked to economic growth (Variable 22). However, there is evidence that per capita requirements for steel stocks saturate around 10 tons per person [25].

Our application of the Sensitivity Model did not result in any strong causes to the use of copper (Variable 2 in Figure 3) among the other variables in the model. However, the major current applications of copper are in electrical wires (about 60%), construction (e.g. roofing and plumbing) (about 25%) and industrial machinery (about 10%) [26]. Wires are used to transport electric energy over long distances and within most electric products. Hence, the expansion of electricity systems (including, for example, the requirement for connecting new renewables capacity to grids) and production of electrical products are important drivers for copper use. Similar to steel, the demand for new buildings, infrastructure, transport equipment, machinery and appliances (very much linked with economic growth) also drives the demand for copper. Copper consumption per capita seems to be linked to GDP per capita - at least until about 12-14 kg per capita .

The pattern of gold use (Variable 3 in Figure 3) is quite different from iron and copper. Most of it is used because of its symbolic value to produce jewelry (about 50%) and for investments such as coins and bars (about 40%) [27]. Only smaller quantities of gold (10%) are used for its technical properties in electronic products, chemical industry, embroidery, etc. The use of gold in jewelry, on the other hand, might be driven to a large extent by the desire to signal status, or by the urge to show love and affection. This is relatively independent from economic growth, although it might be affected by changes in the income inequalities and the distribution of wealth within a country. Coins and bars are used as safe investments during economic disruption. Such gold use is driven by the need for economic safety rather than by economic growth. Gold stocks in countries are constantly traded and not 'consumed' as such in an economy. As a result the net gold import to the EU can fluctuate between large and below zero from one year to another (Figure 2).

The use of virgin metals is also strongly affected by the recycling rate. If kept pure, metals can in theory be indefinitely recycled. It is estimated that some 80% of post-consumer steel is recycled [28]. The recycling rates are the highest for heavy structures, motor vehicles and machinery (85-95%) and lower for smaller appliances and packaging, etc. (around 50%). At present about 38% of high-alloyed steel and 41% of low-alloyed steel used in the economy is from recycled iron and steel [29].

Most of the copper in used products is recovered for recycling because of its high value. However, copper that ends up in steel scrap is lost and unavailable for recycling. Estimates of the total recycling of copper in global post-consumer scrap range from 43% to 53% (UNEP 2011a). At present about 27% of copper demand is satisfied by secondary raw materials.

The gold in coins, bars and jewelry is easy to recycle. Gold on printed circuit boards from electronic products can also be recycled, but requires special sorting and dismantling. The recycling rate of gold in global post-consumer scrap has been estimated to be 96%, if remelting of jewelry and coins is accounted for. If gold in coins, bars and jewelry are excluded the recycling rate might be as low as 15-20% [29].

3.2.2. Barriers to a more efficient use of materials

A barrier to reducing the consumption of virgin metals and competing materials is the predominant business model of prevailing industrial systems. Companies base their revenue on the sale of products. The revenues and profit of the companies typically increase with the number of products sold. This drives an increase in the use of metals and other materials [19]. Barriers to a shift to service- or function-based business models can be found at various levels: among producers (e.g., the perception of the core business of the company and the risks associated with a change in business model), in the markets (e.g., lacking information on the total cost of ownership), and among consumers (e.g., the perception that ownership is necessary to ensure control and availability).

Resource efficiency can be increased through improving circularity by reusing products and recycling components. Barriers to a more circular economy include the labor costs involved, a mismatch between the supply and demand for recycled material, a lack or reverse logistics infrastructure, and reluctance among households to spend much time and effort on source separation of waste.

Resource efficiency can also be increased through making products more material-lean and processes more material-efficient. Barriers to such developments include financial barriers (e.g., lack of capital, requirements on a high return on investments or short payback time, and the fact that old factories and machinery are written off). Other barriers to more material-efficient product designs include economic arguments (it is often cheaper to use larger amount of materials than to carefully design material-lean products), technical requirements (companies often prefer to use extra material to ensure a robust and reliable product rather than carry the risk of product failure), and customer perceptions (a light-weight product can be perceived to have lower quality) [23]. A key component in many of the barriers above is the fact that the highly automated large-scale production of bulk materials has made them relatively cheap compared to the labor costs involved in services, reuse cycles, product design, etc.

A reduction in the use of virgin metals by 80% is a drastic change in the material flows. A policy mix that achieves this target will affect producers of metals and other materials around the world. Manufacturing companies with the traditional business model might lose out, while service-based companies might gain. The implementation of such a policy mix is likely to encounter resistance from incumbent industries that risk losing profitability, from regions and countries that depend on such industries, and from unions with workers that risk losing their jobs. The policy is likely to create new jobs, but perhaps not at the same location and probably not with the same skill requirements. All this creates barriers to implementation of the policy mix.

### *3.3 Promising policy instruments*

The metals policy mix includes five primary instruments:

(1) A tax on all metals and competing materials used in the EU to increase material-efficiency. The tax is introduced at a very low level in 2020 and gradually increased to a level that is high enough to make the construction and manufacturing industry significantly more material-efficient. The materials tax is presented and discussed in Section 3.3.1.

(2) Technical requirements that specify the type and quantity of materials that can be used in specific products are introduced in 2030, with the aim to substitute metals where appropriate, and to increase material efficiency (Section 3.3.2).

(3) Extended producer responsibility schemes are expanded in 2020 to new product groups and countries, with the primary aim to increase recycling but also contributing to material efficiency (Section 3.3.3).

(4) External costs are internalized through gradually expanded and increased environmental taxes from the year 2020, with the aim to improve recycling material efficiency and substitution when these are beneficial for the environment (Section 3.3.4).

(5) Metals-related environmentally harmful subsidies on mining and company cars are removed in 2020, with the aim to make the policy mix more coherent and also to increase material efficiency (Section 3.3.5).

The materials tax, the internalization of external costs and the removal of harmful subsidies are part of a green fiscal reform; the tax revenues and reduced spending are used for funding the rest of the policy mix and for reducing labor taxes. The economic and legal instruments are embedded, supported and, in some cases, preceded by a slightly larger set of softer and/or less controversial supportive instruments (see Figure 4): the funding increases for research and development on recycling and material efficiency (Section 3.3.6); sharing systems and advanced recycling centers are developed to make resource efficiency easier for the public (Sections 3.3.7-3.3.8); education programs are established to retrain the workforce to better fit a restructured economy (Section 3.3.9); and measures are taken to facilitate communication among and between policy makers, business, researchers, and the public (Sections 3.3.10-3.3.12). These supportive instruments aim to reduce the barriers to implementing the policy mix but also contribute to reducing barriers to direct increases in resource efficiency.

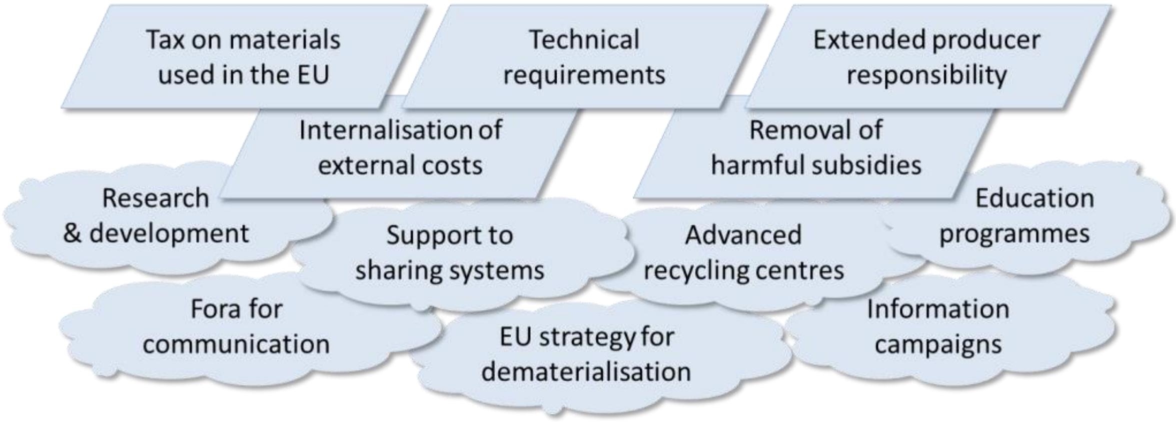



**Figure 4.** Illustration of the policy mix for metals and other materials. It includes a combination of primary instruments (rhomboid) and supportive instruments (cloud-shaped).

3.3.1. Materials tax

The materials tax aims specifically at increasing material efficiency, primarily in the manufacturing and construction industry. It is a tax on all materials that are used in the EU: steel, concrete, paper, polymers, glass, textiles, etc. The materials tax is to be levied on all types of materials in order to avoid burden shifting from metals to other materials. It is levied even on renewable materials because also renewable material resources need to be used efficiently.

The materials tax is levied regardless of whether the material is produced from virgin, natural resources or from recycled raw material. The tax is applied also on recycled material for two reasons:

- Recycled metals, paper and plastics are globally traded goods. Implementing a tax on virgin materials only will make recycled materials relatively cheaper to use in the EU (compared to virgin material). This is likely to shift the use of recycled materials to the EU from the rest of the world. However, it is not likely to significantly increase total recycling. This is because the supply of recycled material is rather insensitive to changes in demand.
- If the tax is applied also on imported material, as we suggest, it is much more difficult to implement on virgin materials only. This is because virgin and recycled materials are often mixed and sometimes impossible to distinguish from each other.

The demand for materials is relatively inelastic. This means that a materials tax needs to be high to significantly affect the material efficiency. Ekvall et al. (2015) [19] suggest that the tax is introduced at a very low level in the year 2020, then gradually increased to 30% of the net value of the material in 2030 and to 200% of the net value of the material in 2050.

In order not to shift materials production outside the EU, the tax will be levied on the material regardless of where it is produced, but not on exported materials. The tax is levied on imported as well as domestic materials in order not to distort the competitiveness of domestic material production in the EU. Exported materials are exempt from the tax in order not to distort the competitiveness of domestic material production outside the EU.

In order to reduce the risk that materials are exported to avoid the tax and then imported again as products, the tax also applies on simple imported products such as wires, pipes, etc., where the materials tax is a significant share of the total production cost (for details, see [19]). The tax exemption is not only for exported materials but also for similarly simple products.

The material tax can take either of two different forms. It could be a value-based tax, which is levied on the traded quantities of finished materials to and within the EU. Alternatively, it could be a weight-based tax levied on the extraction of raw materials from nature and the traded quantities of recovered recyclables to and within the EU. A value-based tax is simpler to decide on and revise because the tax rate is negotiated and decided for all materials at the same time. A value-based tax also automatically reflects the scarcity of different materials to the extent that the scarcity affects the net price of the material. The drawback is that it is not just a tax on the (virgin and recyclable) material resources but also a tax on the labor and capital costs of the materials industry.

The weight-based tax has the advantage that it is a tax on virgin and recyclable raw materials only. In addition, it reduces the volatility of the material costs in the manufacturing and construction industry. This makes it easier for the industry to invest in and plan for material efficient processes and procedures. However, the level of a weight-based tax needs to be separately decided for each raw material and each flow of recyclables. When applied on recyclables it might also create barriers to the collection of recyclable material in the EU.

### 3.3.2. Technical requirements

This instrument entails the development of international standards and of technical requirements for specific metals products and metals components that are sold and used in the EU. These documents regulate the design of these products and components to, for example:

- Improve the modularity to increase reparability and reuse of components, taking into account impacts on energy efficiency.
- Reduce the unnecessary use of material.
- Substitute metals for other materials when appropriate, for example shifting from copper water-piping to polymer piping.

### 3.3.3. Extended producer responsibility

The extended producer responsibility (EPR) is the instrument in the mix that specifically aims at increasing materials recycling. A supply of recyclable material is a prerequisite for recycling of all materials. For metals and paper, where a global market for recycled materials is well established and where recycled and virgin materials compete in many applications, an increase in the supply of recyclable material is the most effective way to increase global recycling.

The EPR means that producers in a broad sense are given the responsibility for securing a specified level of collection and recycling of their own products and packaging. A system of EPR is already implemented in the legislation of several Member States. Our policy mix includes an expansion of EPR to additional product groups (and to materials rather than product groups) in all Member States.

The EPR scheme is funded through fees from the producers. For packaging and some products, a material-specific fee is charged per kg of mass. For other products, a specific fee will be charged per item. This basic set-up will be common all through EU. However, individual Member States are allowed to organize the EPR scheme in a way that fit the national conditions. They can also vary the charge per item or kg depending on the design of the product to stimulate design for recycling and material efficiency.

3.3.4. Internalization of external costs

The internalization of external environmental costs is part of a green fiscal reform in this policy mix. It is based on the Polluter Pays Principle and entails a gradual increase in taxes and fees on emissions and natural resources until all environmental costs are internalized.

The increased environmental taxes discussed here are not metal-specific but are also levied on other natural resources that are extracted in Europe (raw materials, energy and water) and on emissions that occur in all economic sectors in Europe. This will help form a coherent package, increase material efficiency and, at the same time, avoid simply shifting of environmental burdens from the metals industry and metals products to other sectors or commodities:

- Raw materials: these include metal ores, but also the raw materials used to produce materials that clearly compete with metals (concrete, wood, etc.).
- Energy resources: a significant share of the energy resources are used to produce commodities for metals production (coal used to produce coke for crude-iron production, fuel used to produce electricity for primary aluminum production, etc. [30]. Oil and natural gas are used for producing polymers that compete with metals in certain applications. Energy resources used for other purposes are also relevant to include, because shifting from metals to other materials might affect the demand for energy resources in the manufacturing, use and waste management of the products. Including all energy resources in the instrument safeguards against simply shifting from metals products to products and services with a higher energy demand in these parts of the product life cycles.
- Water: water use could be affected when shifting from steel products to wood or other materials based on biomass. A shift from metals products to other solutions might also affect the water used in the manufacturing and use phase of the products. These effects might not be significant, and the external costs associated with the use of water are probably the least clearly connected to metals. However, the external costs of water use are still included in the instrument, partly to form a coherent whole and to safeguard against unknown risks of burden shifting.
- Emissions: metals production and metals processing are important point sources for emissions of, for example, $CO_2$ and heavy metals. The production of competing materials, such as concrete and polymers, is also associated with significant emissions. Shifting from metals to other materials will affect the emissions from manufacturing, use and/or waste management of the products. Including all emissions in the instrument safeguards against simply shifting from metals products to products and services with a higher environmental impact in the life cycle as a whole.

The environmental taxes will be specified per kg of pollutant or ton of material. It will be paid to the national government. The revenues will be used to fund other policy instruments in the policy mix and to reduce taxes on labor.

The implementation of the environmental taxes will be spearheaded by a coalition of the willing Member States. It will be expanded until, eventually, all of EU has implemented the instrument.

3.3.5. Removal of harmful subsidies

A complementary part of the green fiscal reform is the removal of two environmentally harmful subsidies: limited liability for accidents related to metals extraction, and subsidies associated with the purchase of company cars. These subsidies are selected here because they are both related to metals. They affect they mining of metals ores and the size and number of cars.

The money saved through the removal of these subsidies will be use for reducing the tax on labor, just like the material tax (Section 3.3.1) and the environmental taxes (Section 3.3..4). The monetary flows involved in the harmful subsidies are likely to be small, compared to the taxes.

Macroeconomic and environmental impacts are also likely to be small. However the instrument can still be important to form a coherent and comprehensive green fiscal reform.

3.3.6. Research and development

This instrument implies continued and strengthened public funding of research and development (R&D) in EU-27 for recycling and material efficiency. The R&D for recycling will include:

- Design for recycling;
- Efficient and consumer-adapted systems for collection, and identification of the role for the public sector in ensuring their provision;
- Technology for dismantling and separation of components and material; and
- Technology for recycling.

The R&D for material efficiency will include, for example:

- improved processes and products;
- new business models; and
- non-material alternatives for safe investments.

The objective of the last item in the list is to find ways to substitute metals, particularly gold, with other ways of delivering the service safe investments.

3.3.7. Support to sharing systems

Sharing systems for cars, bicycles, tools, and equipment are established by local authorities or through economic support to private initiatives. The sharing systems for bicycles, cars and tools will mainly be set up in urban areas, including cities, towns and larger villages. Sharing systems for agricultural equipment will be established in rural areas.

A combination of the following options will be implemented, depending on local and national conditions, etc.:

1. Local authorities set up a scheme for sharing of cars, bicycles, tools, and equipment.
2. Local authorities support the setting up of private sharing systems through funding of part of the investment cost.
3. National authorities support the private sharing systems
    a. through deductions in income tax to consumers for the renting costs, or
    b. through a differentiation in VAT between goods and services.

This is part of a package to make leasing and sharing of products more convenient, compared to owning the same products.

3.3.8. Advanced recycling centers

This instrument aims to increase reuse and recycling and also to decrease the demand for products through increased longevity. Its objective is to increase collection of waste for recycling and also to facilitate second-hand trade, repairs and redesign of used goods.

This instrument implies that local or national governments support community initiatives aimed at enhanced reuse, and invest in advanced recycling/reuse centers that include:

- Facilities for collection of recyclable fractions.
- Second-hand shops of building components, clothes, furniture, etc.
- Repair shops for furniture, bicycles, tools, etc.
- Shops for redesign of waste products into art or new useful products.

Visitors to the recycling centre are welcomed by personnel who help them to search the waste for items that can be reused, repaired or redesigned rather than discarded [31]. In addition, businesses are encouraged to work with the recycling/ reuse centers to identify products capable of reuse, reconditioning, and re-entering the market.

### 3.3.9. Education programs

This supportive instrument aims to reduce the barriers related to unemployment and a mismatch between the workforce and the skills required as the policy mix shifts the structure of the economy from production of materials and goods to services and new business models. It includes the development and implementation of programs for retraining of workers in sectors where unemployment is likely to occur in order to give them the skills required in sectors that are likely to grow.

The EU also develops a strategy for mainstreaming resource efficiency aspects into relevant academic and vocational curricula (economics, engineering, marketing, architecture, design, business accounting, land management, craftsmen, etc.) and training for professionals to develop skill and techniques relevant for implementing resource efficiency measures in existing firms or developing new business models. The Strategic Energy Technology (SET) Plan Roadmap on Education and Training could provide a useful blueprint [32].

It is important to address both white collar and blue collar jobs. Therefore, the skill enhancement program will have to have targeted programs, contents and design for (i) professionals and leaders responsible for strategic decisions, implementation of innovations, etc, and (ii) broader programs which provide workers with "green" skills suitable for the new business models. Thus, both the necessary changes on managerial and leadership level can be initiated as well as the swift reallocation of workers can be organized which is a necessary part of the decoupling.

### 3.3.10. Fora for communication

This instrument aims to facilitate communication throughout the value chain of priority products, to enable innovation, where current co-ordination structures do not yet exist (as they already do in the vehicle industry). The EU will co-fund the establishment of fora for nations and regions where appropriate, depending on the industrial structure of the value chain. It will co-ordinate an EU level mechanism for value-chain co-operation and co-ordination. Such co-ordination can fulfil several purposes, for example:

- Giving producers and recyclers the opportunity to discuss what quality of the recycled materials can be obtained and what quality of the material is required for different applications. This can serve to establish or strengthen the markets for recycled material and increase recycling level.
- Creating critical mass between purchasers and suppliers in value chains, that allow sufficient purchasers and suppliers to innovate - in the knowledge that their innovation will have a market (suppliers) or will be able to benefit from innovative components (purchasers).

### 3.3.11. Strategy for dematerialization

Developing an EU strategy for dematerialization is a supporting instrument. It aims to change the mind-set of national policy-makers and to pave the way for the material tax and other ambitious policy instruments. The strategy is an official EU document and is primarily an industrial and economic strategy. The process for agreement of the strategy is essential for its political credibility - involving engagement of major industrial groups and Member State economics and finance ministries.

It makes explicit links to the impact of greater resource productivity on macroeconomic change, employment and well-being, in the context of expected low, future EU GDP growth. The development of the strategy should begin immediately, and inform economic performance assessment under the European Semester. The document should be ready and agreed upon by the Member States around the year 2020. It includes the plans for achievement of certain dematerialization objectives in the context of strategic structural change, in particular pointing to the price trends and other market changes which policy will look to deliver to bring about dematerialization. Its goal is to create credible market expectations of change, to give economic actors ample time to prepare for them and change their investment, innovation and depreciation strategies. The document will therefore agree the nature of the instruments to be used to achieve change in market conditions.

3.3.12. Information campaigns

This instrument aims to change the mind-set of the public, authorities, and companies. One goal is to increase public acceptance of the other policy instruments. Another goal is to influence the consumption pattern and related behavior. This can be beneficial for all strategies for reducing the use of all virgin metals through product redesign, increased longevity, and increased recycling. The information campaigns can have broad or narrow topics and targets, for example:

- Counteracting commercials by pointing at alternative routes to well-being that do not involve increased consumption.
- Encourage people to buy jewelry produced from materials with lower environmental impacts than gold.

## 4. Discussion and conclusions

### *4.1 Usefulness of the Sensitivity Model*

We applied the Sensitivity Model as a tool to map the relevant drivers. The procedure of the Sensitivity Model involves a consensus process to agree on the causal relationships between the selected variables. This consensus process offered an opportunity for mutual learning among the participants. We also found the results from the Sensitivity Model useful for illustrating the web of drivers involved in the use of metals. However, the procedure did not generate any new findings. We had already found all facts we used for identifying the drivers in the statistics, the literature and our background knowledge. In our case, the Sensitivity Model did not serve to gain new knowledge, but to structure and present the knowledge we already had.

The number of causal relationships in the Sensitivity Model grows with the square of the number of variables. With 29 variables, there are 29*28 = 812 possible relationships between differnt variables. Finding consensus on such a large number of causal relationships is a cumbersome process. Adding just one more variable would increase the number of relationships to 870. For the procedure to be manageable the number of variables needs to be severely restricted. This means that the Sensitivity Model can only cope with a very simplified model of the extremely complex system that would be affected by our policy mix.

### *4.2 The materials policy mix*

We used the first three steps of the heuristic framework of Givoni et al. [14] to develop the policy mix presented in this paper. A diverse but small author team was given the task to develop the policy objectives, identify drivers and barriers, and select promising policy instruments. We found that the policy mix could be significantly improved through input from stakeholder workshops and other findings of the DYNAMIX project. The EPR and the education programs are inspired by, although not identical to, instruments in the overarching policy mix [19]. Hence, interaction with other researchers, stakeholders and/or policy makers can and should play a role in at least Step 3 in the heuristic framework used.

The policy instruments outlined in the results section jointly serve the purpose to (i) raise the raise the cost of using materials, relative to labor, (ii) increase the supply of recyclable materials, and thus overall (iii) to reduce virgin material use and alleviate supply risks. In our policy mix concept, we aimed at combining primary (key) instruments with supportive instruments in a way that improves the conditions for the primary instruments to better take effect.

As Step (4) in the heuristic framework, the potential effectiveness, impacts, (transaction) costs, feasibility and acceptance of the policy mix are currently assessed in the DYNAMIX project through a mix of quantitative modeling and qualitative analysis. Preliminary findings indicate that the policy mix is beneficial from environmental and health perspectives, and also that it is largely consistent with existing EU legislation and WTO law (see [33, 34, 35]). However, from the assessments and the exchange in the policy mix team some pointers for revising the materials policy mix (Step (5) in the heuristic framework used) emerged and were partly already implemented.

4.2.1 Pointers for revising the taxes

The policy mix will probably not be sufficient to reach the target of 80% less use of virgin metals. This is despite the fact that the policy mix includes at least two strong primary instruments: a high materials tax, and environmental taxes that aim at fully internalizing environmental costs. The uncertainty is large in the quantitative ex-ante assessment of the policy mix, for example because the outcome of supportive instruments such as R&D and Fora for communication is not possible to quantitatively assess.

Unilateral European policies can be expected to have a negative impact on the competitiveness of European industries. This is perhaps particularly true for companies that are severely affected by the environmental taxes in the policy mix. The other strong instrument outlined here, the materials tax, has been designed to reduce the impacts on competitiveness through border-tax adjustments. There might also be an important temporal dimension in the impacts on competitiveness. While *in the short term* we may expect a reduction in competitiveness due to higher production costs, *in the long term* this may result in an advantage due to the implicit and explicit efforts (at firm, industry and economy levels) to boost green innovation and act as a main (or the first) player in a future economic system characterized by constraints to further exploitation of scarce resources.

European companies will also benefit from the reduction in labor taxes that are part of the green fiscal reform. This could serve to shift the structure of the economy from polluting industry and transports to services and to other companies that to a larger extent depend on labor.

A transition to new economic structures has winners as well as losers. The policy mix is likely to at least temporarily increase unemployment in certain sectors, regions and countries. It might also create a surplus of jobs in other sectors or locations, jobs that require a new set of skills. The education program is an important supportive instrument to make the transition smoother.

The ex-ante assessment indicates that the materials tax and the environmental tax are politically contentious, which means they can be difficult to implement [36, 37]. When we presented the policy mix to stakeholders in the DYNAMIX policy platform, the materials tax raised many questions and much discussion. Even if environmental taxes are accepted on a conceptual level, agreeing on the monetary value of environmental/health externalities and pricing the resource depletion risks are likely to be contentious issues.

The policy mix might be particularly difficult to accept because the two taxes partly overlap and can be considered a double taxation of the material-related environmental impacts. Full internalization might not be sufficient to reach an externally given target, such as the 80% reduction in virgin metals use, but it should in theory be sufficient to reduce resource consumption and pollution to levels that are optimal from a societal perspective.

However, in practice there are several barriers to the development towards such an optimum. For example, investments in environmental technology is not the core business of companies. This means that less attention and capital is available and a higher rate of return on the investment is required. As a result investments in efficiency or pollution control are often not made even when they are profitable. Neither producers nor consumers have full knowledge of the total cost of ownership, which means that products tend to be optimized from the perspective of production cost rather than the life cycle cost. A double taxation might help overcome these barriers.

#### 4.2.2 Pointers for revising the EU strategy for dematerialisation

Preparing and implementing the proposed EU strategy for dematerialisation should build on the lessons learnt from the processes around the overhaul of the EU Circular Economy Package, which consists of the EU Action Plan for the circular economy (COM(2015) 614 final) and proposed amendments of several EU Directives (on Waste, Packaging Waste, Landfill, end-of-life vehicles, batteries and accumulators and waste batteries and accumulators, and waste electrical and electronic equipment). Initially launched in July 2014 by Environment Commissioner Potocnik under the Barroso II Commission, it was taken back in late December 2014 in the context of the new 2015 work programme of the incoming Juncker Commission in order to be retabled in a more ambitious version in late 2015, which was finally released on 2nd December 2015.

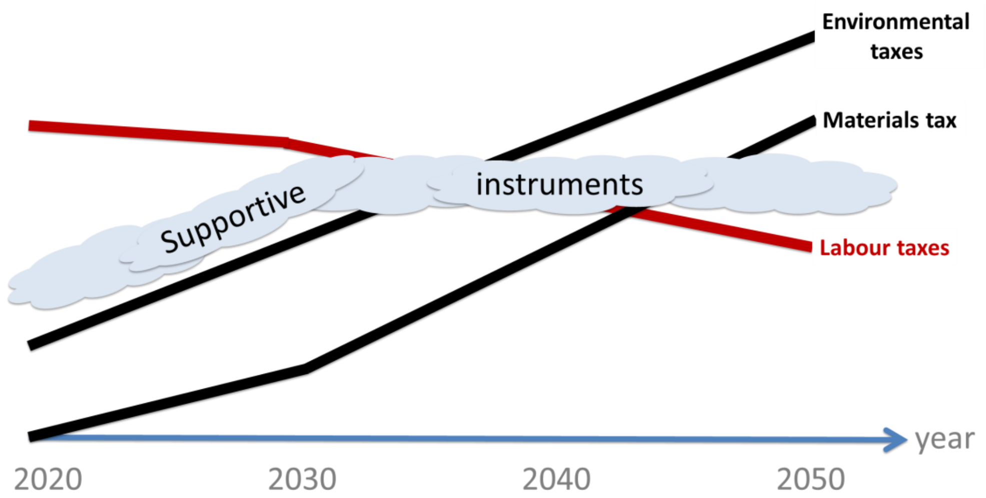
Independent of the many discussions regarding the level of ambition of the new package and harsh critiques from NGOs (e.g., regarding lowered recycling targets for household waste and packaging waste and the removal of any resource efficiency target [38]), this process indicates that preparing EU wide strategies requires strong and long-term coalitions to hold beyond terms of political actors. Furthermore, the fact that the new package grants some Member States longer extension periods for complying with the targets highlights that a longer term focus is needed to envision a more ambitious EU policy on a circular economy.

In this light, it seems at present politically unlikely that an additional strategy on dematerialization will be able to be agreed upon by 2020. In fact, the proposed EU strategy for dematerialisation could be designed as step-wise expansion of the circular economy package to increase coverage of and linkages to resource efficiency aspects and documents (such as the EU Roadmap to a Resource Efficient Europe, COM(2011) 571 final). This would have to include careful monitoring of opportunities when best to introduce to such an expanded package issues of dematerialization contributing to alleviating expected low, future EU GDP growth as well as to improvements in well-being.

#### 4.2.3 Using mitigating and synergetic instrument combinations

The chosen combination of instruments not only minimizes contradictions between instruments (i.e., being consistent), but also it enable synergetic effects and positive interactions (i.e., being coherent) due to the enabling framework effects of the supportive instruments. The instruments in the policy mix are designed to make the two taxes somewhat easier to accept. The materials tax includes border-tax adjustments to reduce the impact on the competitiveness of European industry. The environmental tax is based on the well-established Polluter Pays Principle. Both are part of a green fiscal reform that funds the rest of the policy mix and reduces labor taxes. Both are also raised gradually from the current levels to reach the ultimate level in the year 2050 (see Figure 5).

Even with these measures taken, the ongoing ex-ante assessment indicates that the policy mix will neither achieve an 80% reduction in virgin metals use by 2050 nor be easy to get accepted and implemented.




The **Figure 5.** Qualitative illustration of the dynamics of the monetary flows in the green fiscal reform. revenues from environmental and materials taxes increase gradually. They are first used mainly for establishing the rest of the supportive instruments. However, any surplus is used for reducing labour costs.

*4.3 Concept of policy mixing*

Applying and adapting the heuristic framework for policy mix design proved very interesting in the context of the DYNAMIX project. It allowed us to use different methods for identifying relevant drivers (literature review, the Sensitivity Model, and workshops) and helped guide both discussion on as well as the actual selection of potentially promising policy instruments aimed to achieve a wider set of environmental key targets. The discussion around which primary and supportive instruments to select because of which supposed interlinkages and synergetic effects was instrumental in shaping the understanding of the metals policy mix to be more than the sum of its instruments. And although ex-ante assessments are not yet finalized, their results already indicate the need to think about revising or replacing selected instruments or adding new ones.

Development of consistent and coherent policy mixes can contribute to a more effective strategy for policy-making. However, the concept of policy mixes appears to clash with current political realities and practical experience. Further research from organizational theory and political economy is required to investigate under what circumstances such strategic policy-making would be possible and through which actions its feasibility could be strengthened. Such research could maybe build on action research in practice settings.

Designing politically feasible and yet ambitious policy mixes that have the potential to reconfigure systems remains a formidable challenge. This challenge relates both to their conceptualization and assessment of cumulative effects as well as to reconciling long-term forward-looking policy strategies with political economies of election cycles and diverging interests in dynamic multi-actor settings. We suggest taking on this challenge with further scientific rigor, political creativity and innovative coalitions because combining primary and supportive instruments into coherent and time-dynamic policy mixes appears a promising and enabling step on the way to fostering transition and reconfiguration of systems towards sustainability [39].

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## Abbreviations

The following abbreviations are used in this manuscript:

DYNAMIX: DYNAmic policy MIXes for absolute decoupling of environmental impacts of EU resource use from economic growth (an EU FP7 research project)
EPR: Extended producer responsibility
EU: European Union
FP7: 7th Framework Programme
GHG: Greenhouse gas
R&D: Research and development
RMC: Raw Material Consumption
VAT: Value-added tax
WTO: World Trade Organization

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