Dynamic Modeling of Raw Material Criticality

Basic methodology of criticality assessment

Criticality = Vulnerability   Supply Risk

cf. Definition of classical risk analysis ISO 31000 / 31010:

Risk = Probability of the accident occuring   Expected loss of the accident

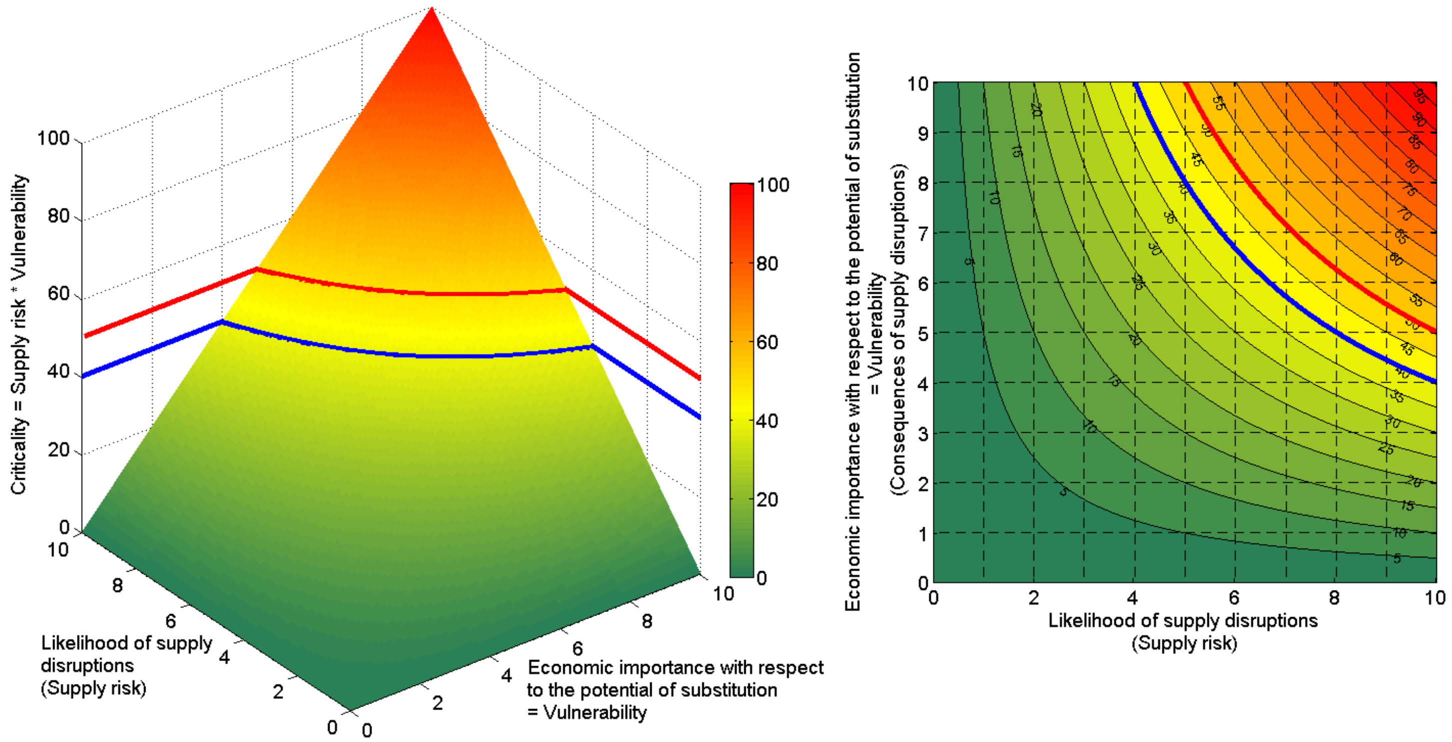

Figure 1: Basic principle of the assessment of raw material criticality within the 'criticality matrix'

Results of previous static analyses

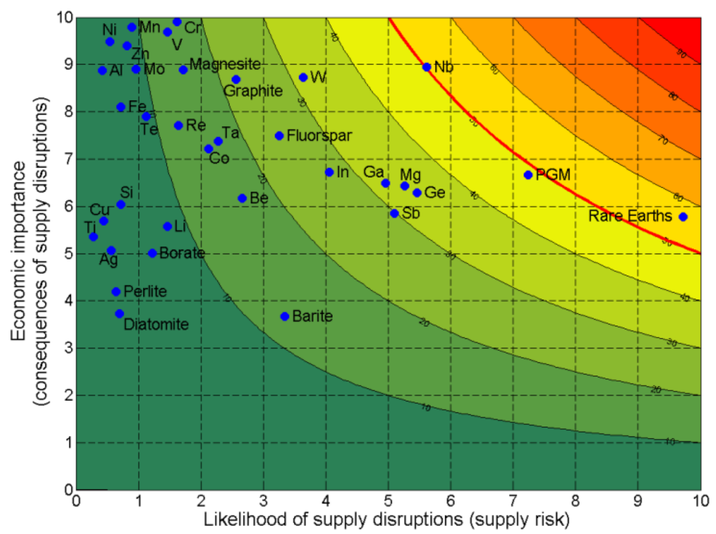

Figure 2: Results of the EU criticality study in 2010[1]

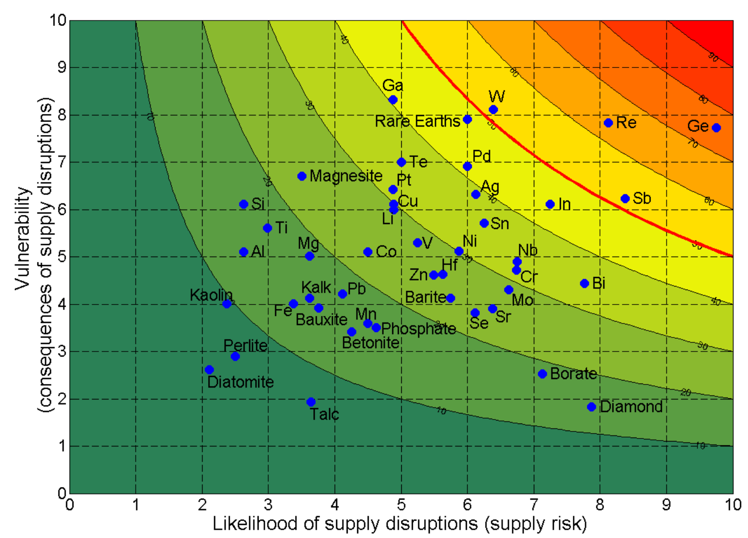

Figure 3: Criticality assessment for Germany in 2011[2]

Towards dynamic criticality modeling

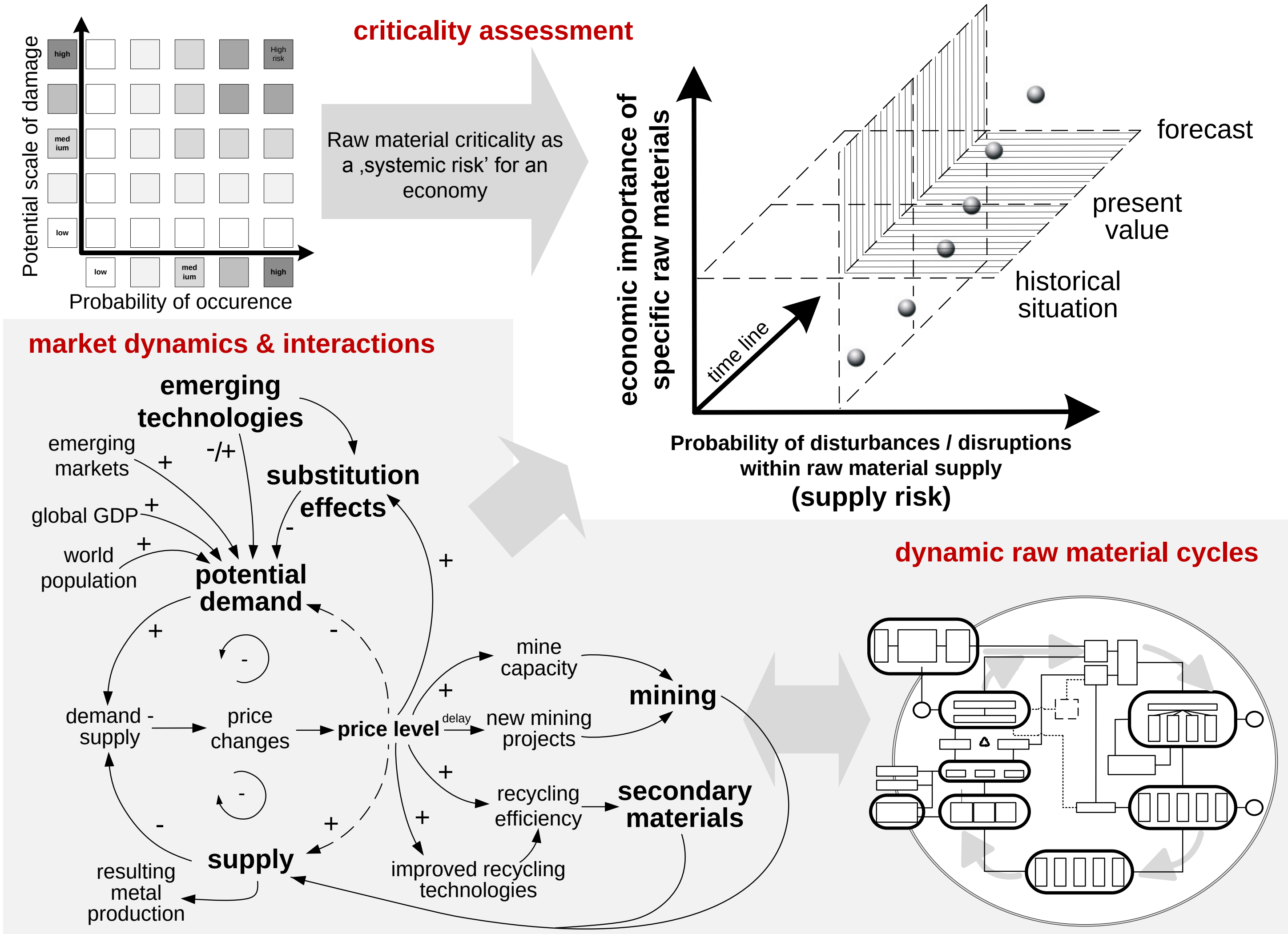

Figure 4: A System Dynamics model to assess raw material criticality over time[3]

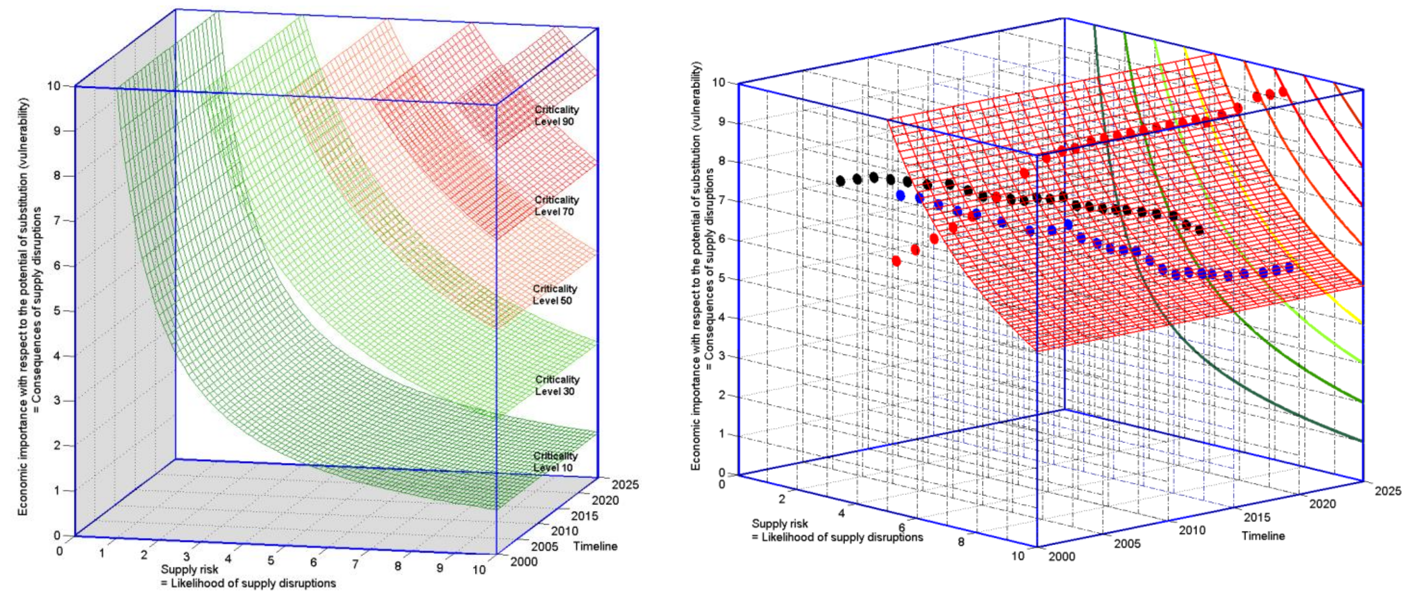

Figure 5: From the 'criticality matrix' to the 'criticality cube' in order to early identify future critical raw materials

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References (cf. www.r-cubed-research.eu):

1: Critical raw materials for the EU: Report of the Ad-hoc Working Group on defining critical raw materials 2010

2: Kritische Rohstoffe für Deutschland, Erdmann et al. 2011

3: Quantitative Analysis of the Criticality of Mineral and Metallic Raw Materials Based on a System Dynamics Approach, Glöser 2012

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Further Developments of SFA Modeling using SD

Regionalization of Global Models

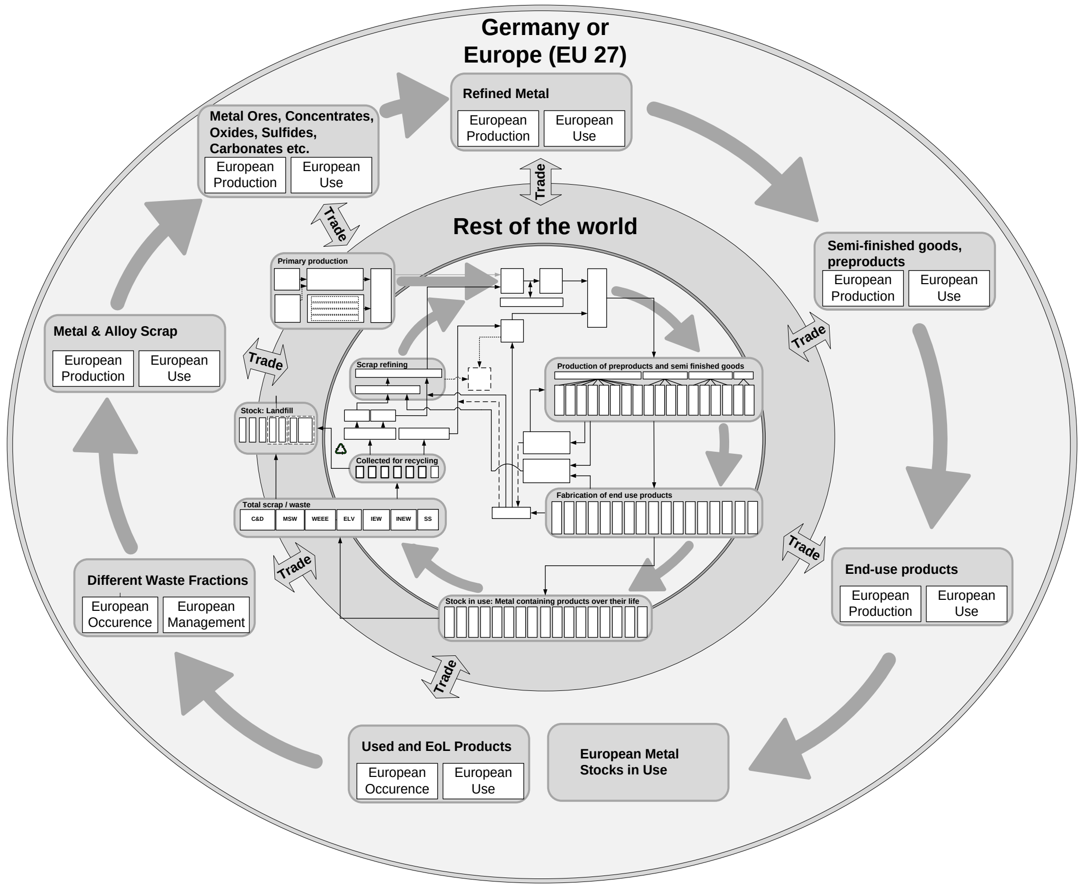

Figure 1: Extension of a global model on a regional scale by breaking it down into a regional and a rest of the world (RoW) part and linking these partial models by means of foreign trade.

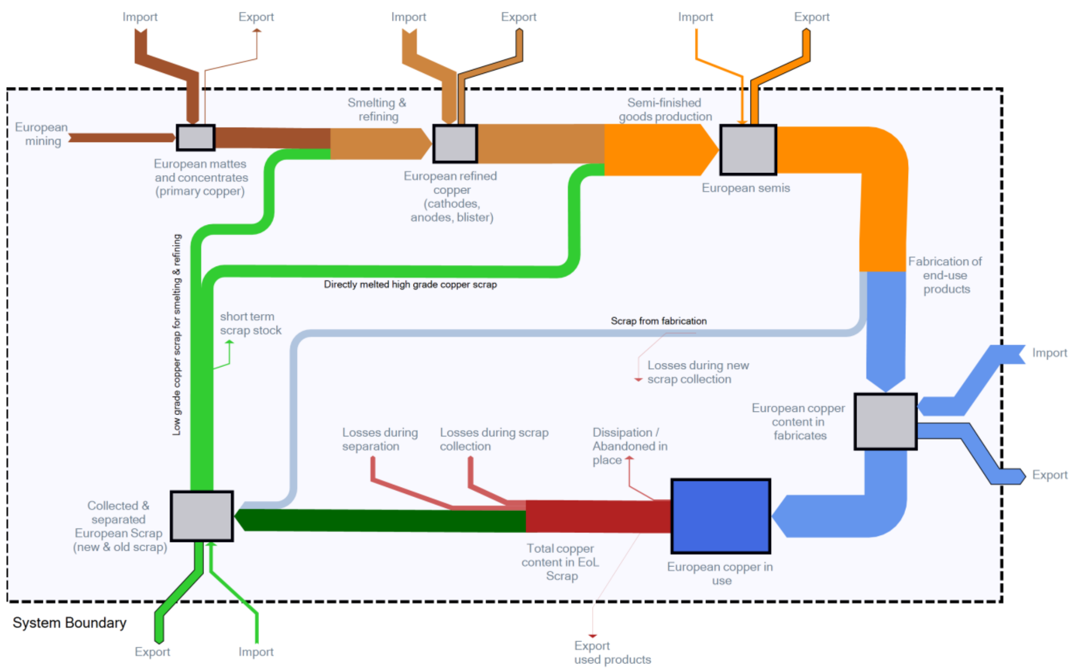

Figure 2: Potential outcome of a regional or national dynamic stock and flow model with consideration of import and export flows at every stage of the life cycle.

Linking related Metal Lifecycles

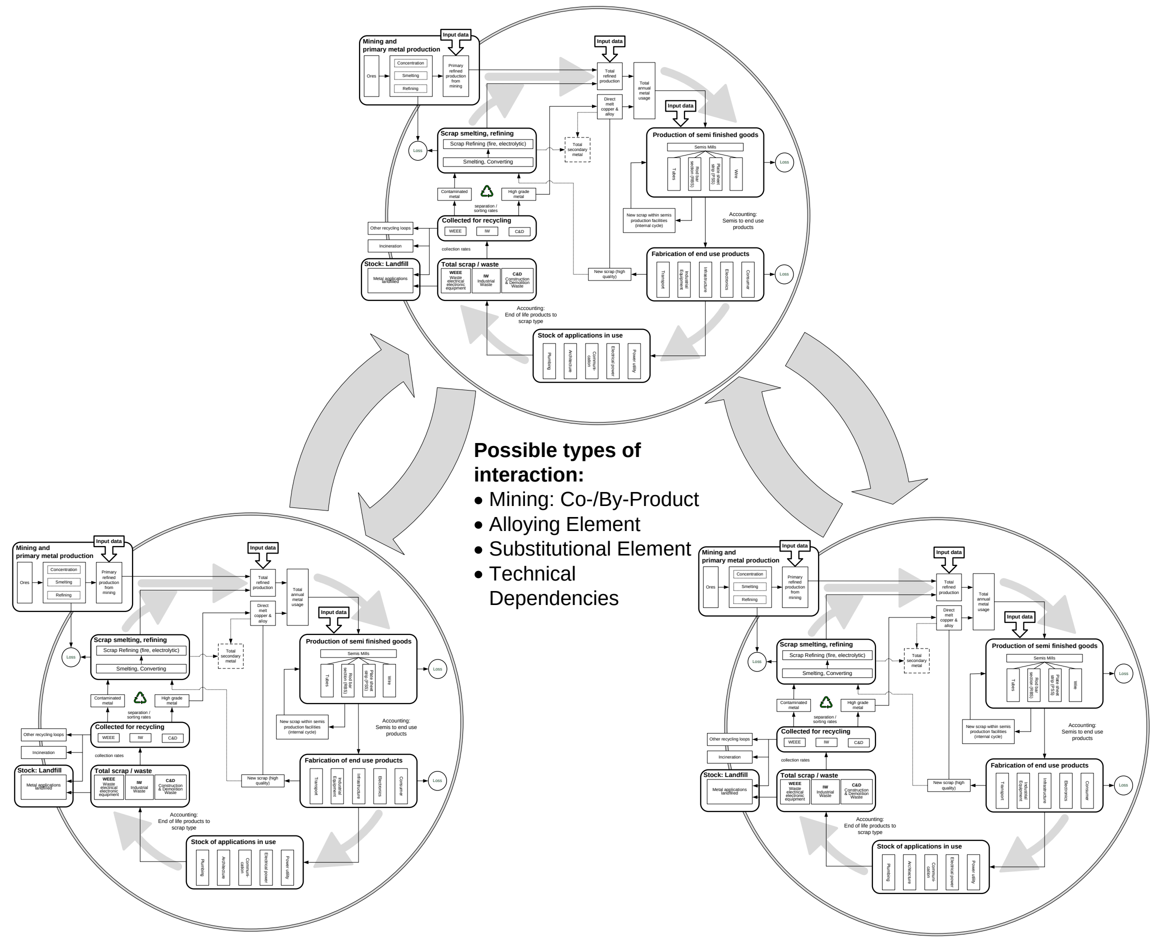

Figure 3: Lifecycles of some metals show interrelations and interdependencies among each other.

Joint primary production if one metal (or mineral) is a byproduct of another metal (or ore) such as tellurium of copper or gallium of aluminium production.

One metal might be an alloying element of another with its demand depending on the demand of the main alloy constituent such as manganese for aluminium alloys or nickel and chromium as important alloying elements of steel.

One metal might be a substitute for another metal in specific technical applications such as aluminium as a substitute for copper in specific electrical cables.

The demand for several metals might depend on specific technologies such as lithium and cobalt for lithium ion battery production

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Linking Raw Material Cycles and Market Models

Causal loops on raw material markets

When developing a qualitative causal loop diagram, one can imagine numerous feedback effects, particularly concerning feedbacks from the price level of a metal to both primary and secondary supply (mining & recycling) and to the demand side in form of higher resource efficiency and the potential use of substitutes.

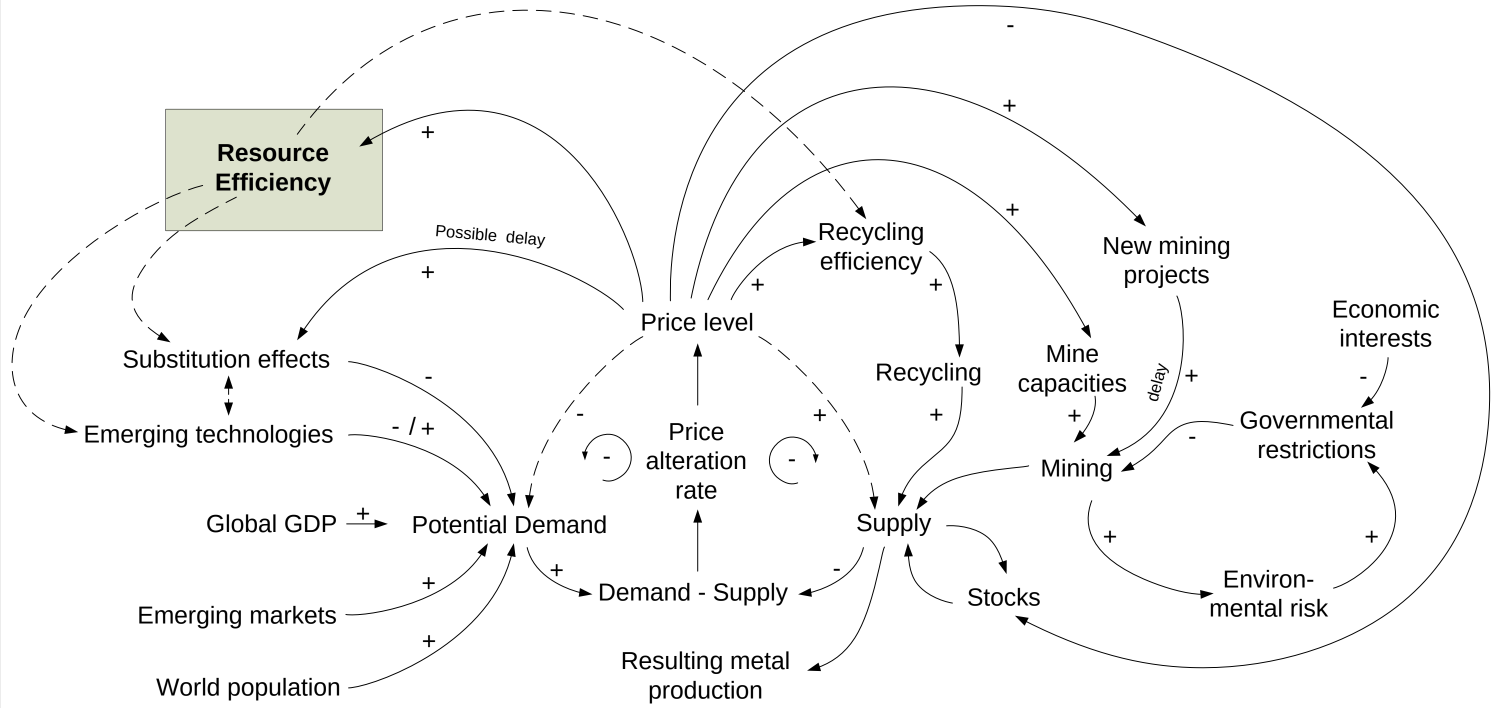

Figure 1: General causal loop diagram of potential interdependencies and feedback effects on raw material markets

The main challenge of this basic approach is to keep the specific market balanced despite external influences such as economic and technical development. However, the basic principle of a market equilibrium in microeconomics may be applied to a system dynamics model as illustrated in Figure 2.

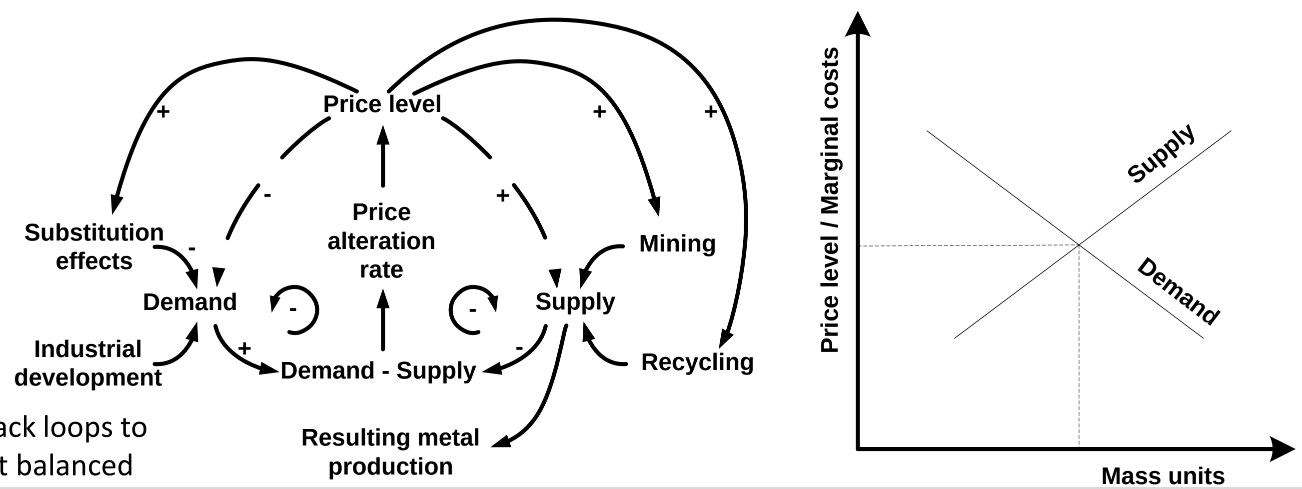

Figure 2:
Negative feedback loops to keep the market balanced

Linking metal cycles and market models

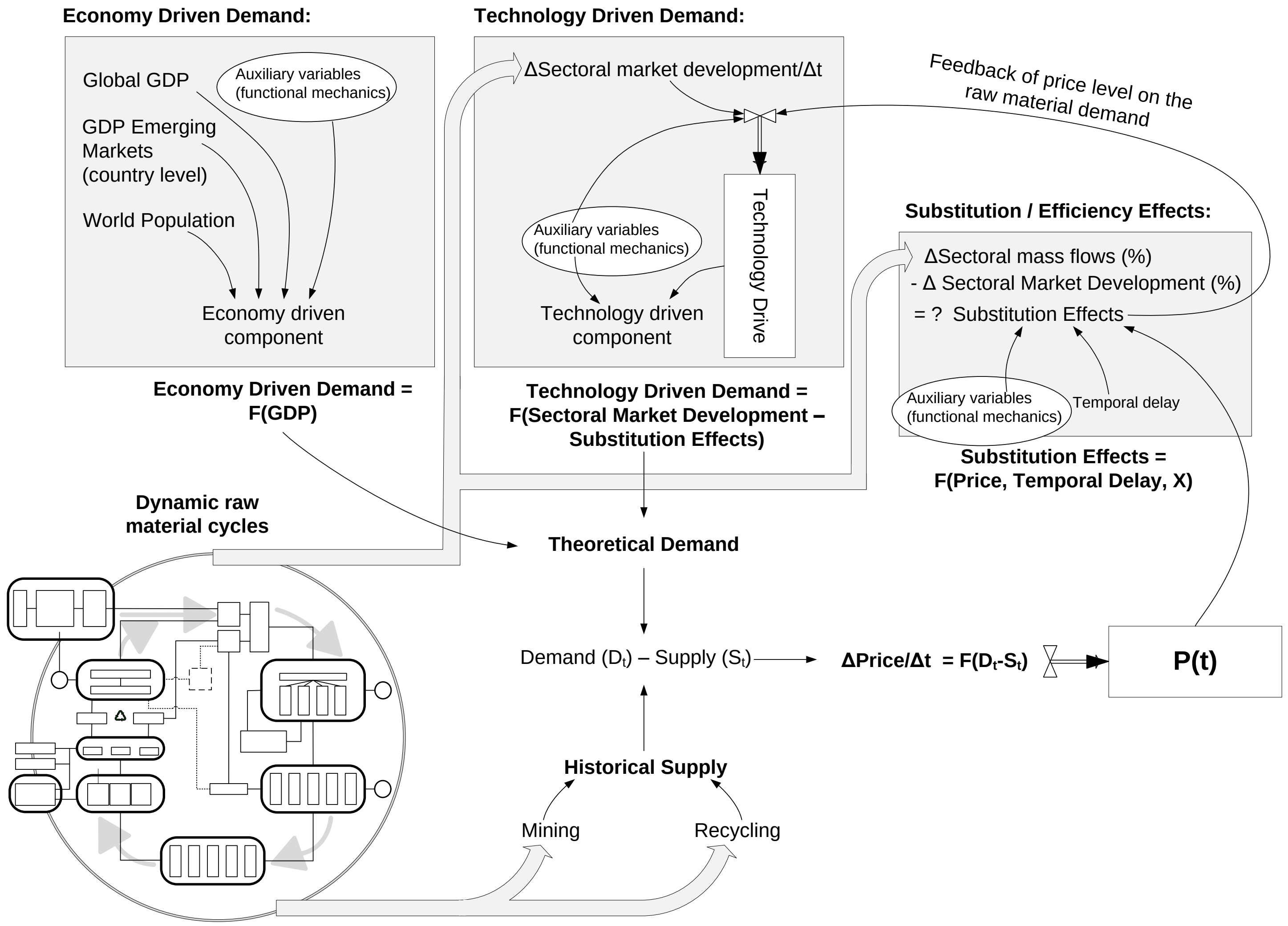

Figure 3: Linking physical material flow models with macro economic and technical demand drives and analyze the feedback of higher raw material pricing on raw material demand through substitution effects

Analyzing material needs in the context of economic development and assessing the feedback of potential material shortages and high raw material pricing on the development of specific technologies (concerning both high tech innovations and new recycling potentials) is one of the main future challenges of industrial ecology. We are convinced that both pure system dynamics models (consisting of delay functions and systems of first order differential equations) and hybrid models combining the system dynamics approach with econometric models will strongly contribute to a better understanding of current developments on raw material markets.