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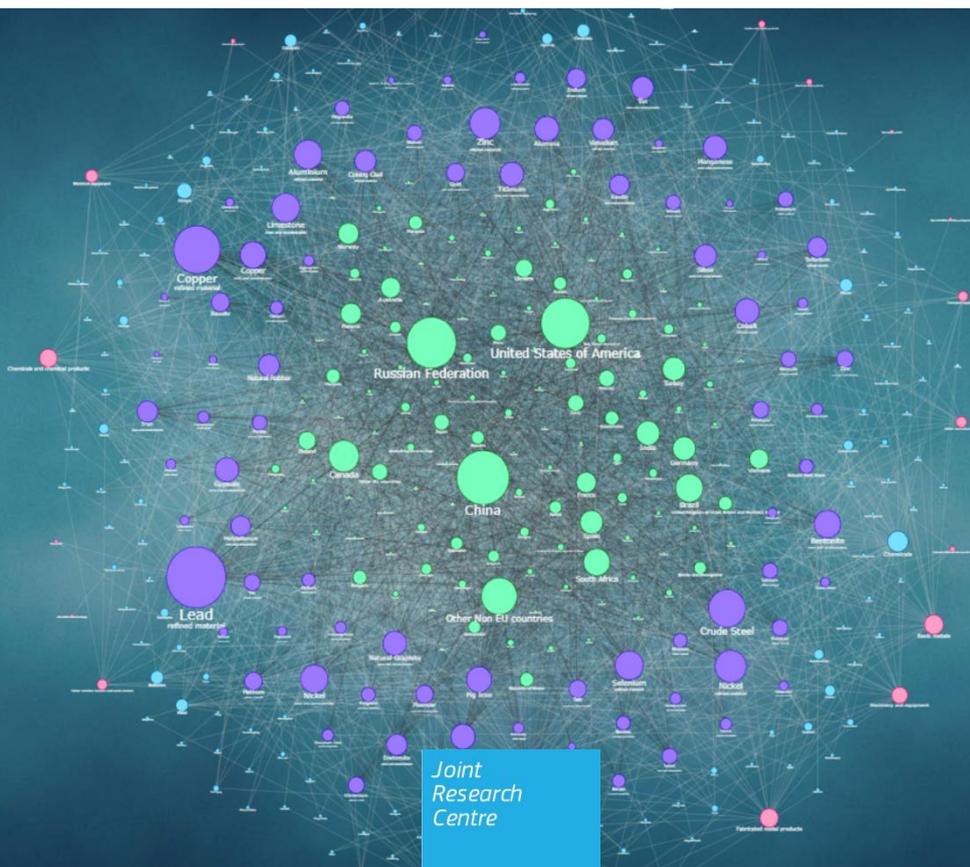
JRC TECHNICAL REPORTS

The Raw Materials Supply Chain Viewer

*Designing and Developing
a Data-driven Graph-
based Application for
RMIS*

Theodor Ciuta and Constantin Ciupagea

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Abstract

This report offers a description of the IT application designed for the visualization - in an interactive manner - of the raw materials supply chains. This tool, namely Raw Materials Supply Chain Viewer (SCV), consists of full stack web application developed for the EC's Raw Materials Information System (RMIS) using a special graph-database engine and a force-directed visual application.

This web application allows for searching and visualizing four types of categories of interest along the supply chain of a certain raw material: other raw materials involved along the supply chain; sectors (industries) which are intensively using the specific raw material; countries that are involved in the supply chain, either as main supplier or as main consumer; end-use applications that are technologically dependent on the specific raw material. The SCV also allows for combining multiple raw materials supply chains for exploring different viewpoints and interconnections.

The SCV represents a valuable analytical tool for assessing the product complexity belonging to various material supply chains, key countries supplying different raw materials or node interconnections at the level of end-use applications and industrial sectors. The interactive IT application allows for a flexible search of aspects of interest along a specific value chain, enhancing the attractiveness of the RMIS and easing the knowledge management activities.

The SCV application is currently integrated into the RMIS platform, in the *Industrial Value Chains & Material Flows* module, directly available at <http://rmis.jrc.ec.europa.eu/apps/scv>.

1. Introduction

The importance of analyzing industrial value chains is becoming explicit in the recent European Commission policy documents, whether we talk about strategies, action plans or binding decisions or directives. It is also evident that, since the establishment of the European Innovation Partnership on Raw Materials (2012¹), the number of EU strategic documents referring to the importance of non-fuel non-agricultural raw materials (both abiotic – mainly minerals - and biotic), with respect to their circularity, to their security of supply or to their sustainable and responsible sourcing, multiplied at an accelerated rate. The security of raw materials along their entire supply chains is mentioned in dedicated sections by the Circular Economy Action Plan (2015²), by the European Defence Action Plan (2016³), by the renewed industrial policy strategic document (2017⁴). The European Commission started in 2011 the publication, every three years, of a Communication on the EU List of Critical Raw Materials, for which a number of around 80 raw materials are scrutinized as potential candidates for being declared critical for the EU economy, based on a methodology lately improved by JRC⁵ and an assessment which was supervised also by DG GROW and DG JRC (starting 2020, the JRC will perform the entire assessment exercise).

There is growing concern in relation to the increasing use and high supply risk of critical raw materials (non-fuel, non-agricultural) in the case of the European economy, including bottlenecks and associated risks hindering their supply chains.

The energy transition process that started on international markets as a consequence of global decisions related to climate change goals, also following turmoil and policy measures taken on global energy markets, is supposed to be particularly strong in Europe. It has already generated numerous measures aimed at reducing energy consumption, carbon emissions, which led to an upward push for innovations, technological substitutions and novelties, increased use of renewable energy related products. Most of these new technologies are, however, substituting the use of energy and energy-related products with the use of more non-fuel, non-agricultural raw materials (particularly the critical ones). It is very likely that in a few years, the world will start talking about the crisis of some minerals, with Europe being severely hit by the increased global competition for access to a sustainable supply of these raw materials, because of its low level of self-sufficiency and high level of consumption of products which are rich in critical raw materials.

The only viable response for the EU stays in unity and in building a common approach to this potential increased scarcity and risk. It took EU around 40 years since the 1971 oil crisis to see a solid project for an Energy Union in Europe coming to life. It may take less, but still a long time period to reach an agreement between EU Member States on a "Raw Materials (Minerals) Union". In the case of several critical raw materials, the degree of concentration at world level is close to 100 % in one country (unique world supplier), which by default contains premises for future conflicts and warzones, depending on the

¹ Making raw materials available for Europe's future wellbeing; proposal for a European Innovation Partnership on Raw Materials – COM(2012) 82 final

² Closing the loop - An EU action plan for the Circular Economy - COM/2015/ 614 final

³ COM(2016) 950

⁴ Investing in a smart, innovative and sustainable Industry: A renewed EU Industrial Policy Strategy - COM/2017/0479 final

⁵ Assessment of the methodology for establishing the EU list of critical raw materials; Methodology for establishing the EU list of critical raw materials; Guidelines – Study, JRC team, ISBN 978-92-79-68051-9, 2017

importance of these resources to other economies. This makes the analyses and the research studies dedicated to the supply chains of these raw materials extremely valuable for future decision making, from the primary sourcing till the end-of-life phases, paving the way to recycling the materials or prolonging their life throughout the economic processes. Important stages of the supply chain of any raw materials are also those stages in which the economy's demand focuses on products that are rich (content-wise) in the specific raw material. Offering information on the value chains of these products and tools for understanding and interpreting this information can reduce significantly the length of policy making processes.

Responding to an action included in the Circular Economy Action Plan, the JRC is further developing its pilot project initiated end-2014, the Raw Materials Information System. By the end of 2017, under policy supervision of DG GROW, the version 2.0 of the RMIS⁶ was launched during the Raw Materials Week in Brussels and since then, JRC continuously enhanced the content and the format of this knowledge management tool and of its associated website, which became the EC Raw Materials Information System, for which maintenance and further development JRC is responsible.

The EC RMIS has sections (tiles) dedicated to raw materials profiles, country profiles addressing specific raw materials aspects, secondary raw materials, critical raw materials, industrial value chains for priority products in the EU context, a gateway to link with stakeholders, data providers and partners. JRC developed the RMIS Information System infrastructure in a modular manner, in order to allow for the use of several interactive IT tools to enhance the visual quality of the site and increase through personalized use the value added of the information displayed by RMIS. A good example of such an interactive tool is the Supply Chain Viewer (hereinafter: SCV), whose IT features, structure and capabilities are described in this document.

The theoretical (conceptual) background information on the SCV proposed by JRC for visualizing and then analyzing a supply chain for a certain (critical) raw material was first described in a previous JRC paper (technical report)⁷ in 2017. The original concept departed from the visualization of the main variables defining a specific critical raw material along its supply chain, in volume terms. The current report offers a description of the IT tool designed for the visualization in an interactive manner of the data characterizing the supply chains. Obviously, such a tool could be used in visualizing similar circular processes and extended to cover not only volume term figures/data, but also value terms data.

⁶ see website <http://rmis.jrc.ec.europa.eu>

⁷ Nuss, P., Ciuta, T., Visualization of Raw Material Supply Chains using the EU Criticality Datasets: Development of a Supply Chain Viewer for the EU Raw Materials Information System (RMIS), Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-85756-0, ISSN 1831-9424, doi:10.2760/751342, JRC 111646

Node example:

```
{
  id: nodes/CHN,
  rev: _Xp_YPAy-z,
  key: CHN,
  "label": "China",
  "type": "country",
  ... <other properties>
}
```

Link example:

```
{
  id: links/2311484,
  rev: _Xp_Yil2-A3,
  key: 2311484,
  _from: nodes/Aerospace,
  _to: nodes/Transport_equipment,
  "data_src": "CRM 2017",
  "det1": "EU end uses",
  "networks": [
    {
      "sc": "Re",
      "value": 83
    },
    {
      "sc": "Ta",
      "value": 21
    },
    {
      "sc": "Ti",
      "value": 8
    }
  ],
  "type": 3,
  "type_desc": "used in",
  ... <other properties>
}
```

From these examples, it is evident that the quantitative data is comprised in the connecting links entries and not in the nodes entries.

A single material flow represents a chain of nodes and links starting from a country node, passing through a material node, an application node and ending to a sector node, each node being connected to the next one by a directed link:

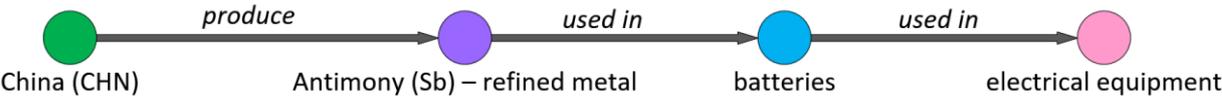


Figure 2. A single material flow (example)¹².

All the flows that pass through one material node are composing one material supply chain, corresponding to that material:

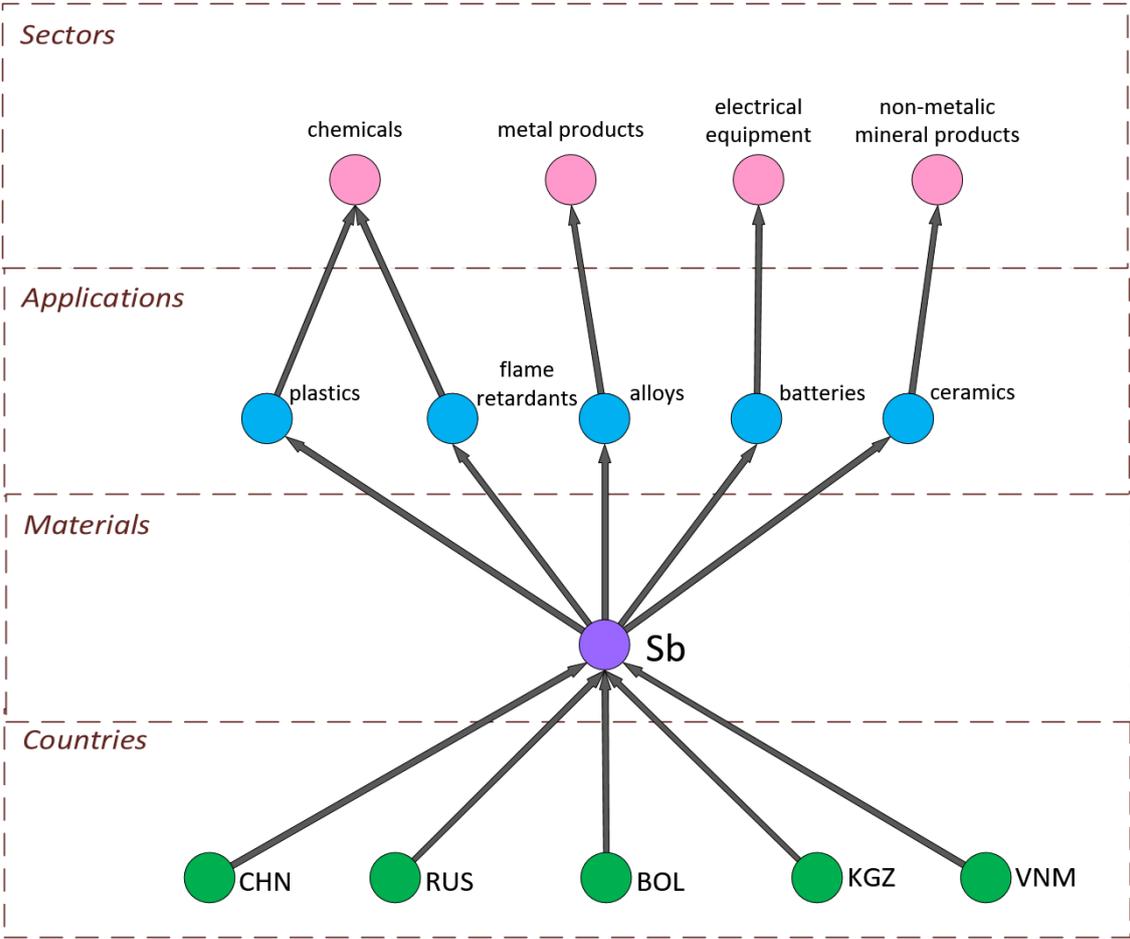


Figure 3. The supply chain of Antimony (Sb) – graph view only, without quantitative details.

Most of the applications, countries and sectors nodes belong to more than one material supply chain. By example, the node Argentina (ARG) is linked to other nine material nodes (as Argentina is supplying nine materials in the whole supply chain network as copper, lithium, zinc etc.).

¹² As described in Nuss & Ciuta, 2018

2.2. Graph Generation

All the above-mentioned flows – including all nodes and all connecting links – compose the entire (whole) supply chain graph. From this whole graph there are programmatically extracted custom subsets/subgraphs corresponding to different views requested by the front-end user¹³.

Whole SCV graph properties:

- **directed** (or digraph) is a graph that made up of a set of nodes connected by edges, where the edges have a direction associated with them.
- **oriented** graph is a directed graph having no symmetric pair of directed edges
- **connected** graph is a graph with no unreachable nodes.
- **acyclic** is a graph having no graph cycles

2.3. Graph Traversal

The graph traversal operation is used to extract a certain material supply chain (subgraph) from the whole SCV graph.

This technique consists of systematically traversing the links of the whole graph such that every link is traversed exactly once and each node is visited at least once by filtering the nodes and links that satisfy certain criteria. In our case, the criterion represents the membership of the links to the requested supply chain¹⁴.

This operation is executed on the back-end (server), following a request from the user (selection of a certain material supply chain). Logically it runs the following algorithm:

1. Start from V_{sel}
2. Walk $V \rightarrow \{E\}$ inbound + outbond
3. Filter: $E \in SC$
4. Retain unique (V, E)
5. Return all selected sets $\{E\}, \{V\}$

where (V,E) represents a node-link pair, V_{sel} the starting point, $\{E\}$ the links array and $\{V\}$ the nodes array.

Internally, the ArangoDB engine executes this traversal operation using DFS (depth-first search) algorithm.

In the Figure 4 the red links and nodes are extracted by graph traversal operation that belong to a certain supply chain (in red).

¹³ For further details on graph modelling for NoSQL db, see Frisendal T., 2017, Chapters 3 and 4.

¹⁴ Deo N., 2016

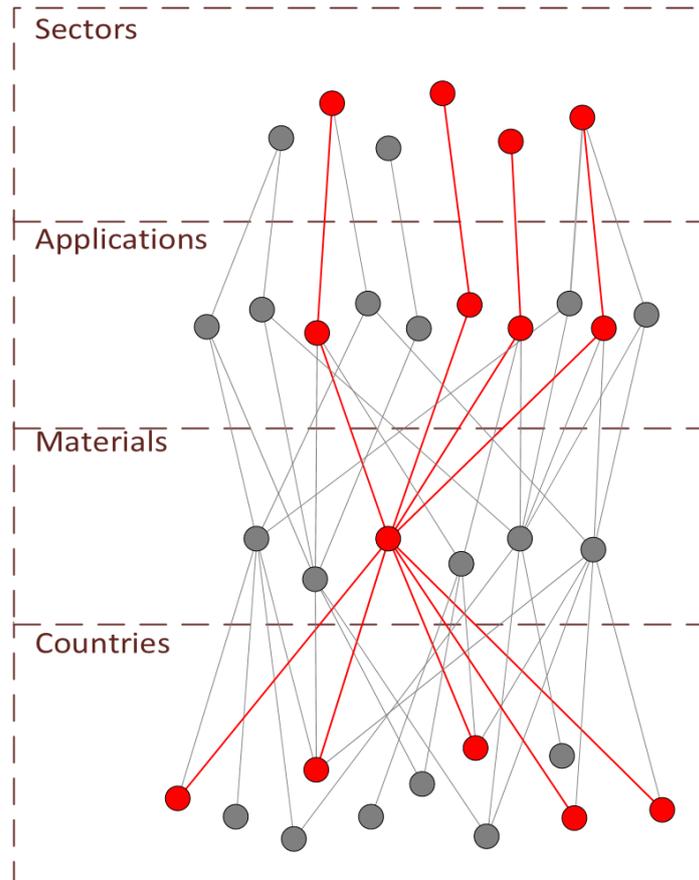


Figure 4. Graph traversal operation example: results in extracting a single material supply chain/subgraph (in red) from the whole graph.

The query returns to the front-end a double set of nodes and connecting links that represents the supply chain/subgraph of the requested material that will be further processed the displayed by the front-end view application.

Likewise, the same algorithm is used to extract the data for the Overlaid View. In that case, however, the filter at step 3 will be $\mathbb{E} \in \{mSC\}$, where $\{mSC\}$ is an array consisting of the selected supply chains requested by the front-end application (user's choice).

2.4. Direct Neighbours

Using the graph direct neighbours operation it is possible to extract the Individual nodes views for Countries, Applications and Sectors: for a chosen node, the database engine will return all its directly connected nodes along with their connecting links.

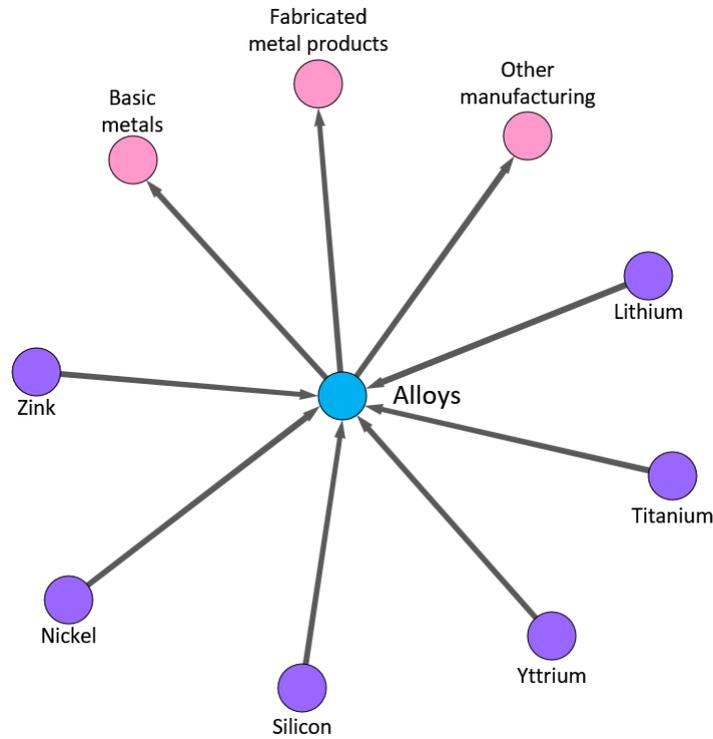


Figure 5. Sub-graph: one material node and its direct neighbours.

3. Data Management Microservices and RESTful API for Data Transfer

ArangoDB provides a powerful RESTful¹⁵ API (Application Programming Interface), named *Foxx Microservices*¹⁶, for designing customized http queries from either back-end or front-end applications. ArangoDB exposes its API via HTTP(S), making the server accessible easily with a variety of clients and tools (e.g. browsers, curl, telnet). ArangoDB uses the standard HTTP methods (e.g. *GET*, *POST*, *PUT*, *DELETE*, *PATCH*) as described in [RFC 7231](https://tools.ietf.org/html/rfc7231)¹⁷. The ArangoDB is dispatching back data from request in JSON format.

The Foxx microservice framework makes it easy to extend ArangoDB's own REST API with custom HTTP endpoints using modern JavaScript running on the V8 JavaScript engine. Foxx allows writing data access and domain logic as microservices running directly within the database with native access to in-memory data.

The SCV API presents a REST endpoint on the server (back-end) that responds to four categories of HTTP GET/POST requests:

- GET <whole graph> : delivers to the front-end a response contains the whole SCV graph without links details (data used to render the main entry view of the application, Whole Supply Chain Network)
- POST <SC>: delivers the sub-graph of one SC; the requested SC is specified in the POST request body (data used in Material Supply Chains views)
- POST <one node>: delivers a sub-graph containing the requested node and its neighbours (data used in Individual Node Views)
- POST <multiple SCs>: delivers a sub-graph containing multiple interconnected SCs; the requested SCs are specified in the POST request body (data used in Overlaid Views)

This API is used to communicate through REST web services (by delivering graph data on request) from the database server to the front-end application. The HTTP body of replies from the API includes the data in the format of array of JSON objects (see Figure 6). The headers of replies includes either a status code *OK 200* (The request was fulfilled), or various error codes, as code 500 (Internal server error), code 204 ("no content") or general ArangoDB storage/transactions errors.

¹⁵ Representational State Transfer

¹⁶ More details about Foxx on <https://www.arangodb.com/why-arangodb/foxx/>

¹⁷ <https://tools.ietf.org/html/rfc7231#section-4>

4. Web Application

The Web user interface (UI), which runs inside the user's web browser, contains the SCV web application that controls and renders the visualizations, information panel, menu and buttons, and handles the user interaction with the application's engine.

The SCV web application is developed in JavaScript (js) and uses several open-source libraries:

- Vue.js – a reactive JavaScript framework library for building user interfaces and SPAs¹⁸
- D3.js – a JavaScript library for producing interactive data visualizations in web browsers.
- Axios.js – a JavaScript library used to make complex HTTP requests from a server-side REST API (Foxx, the ArangoDB's own REST API)

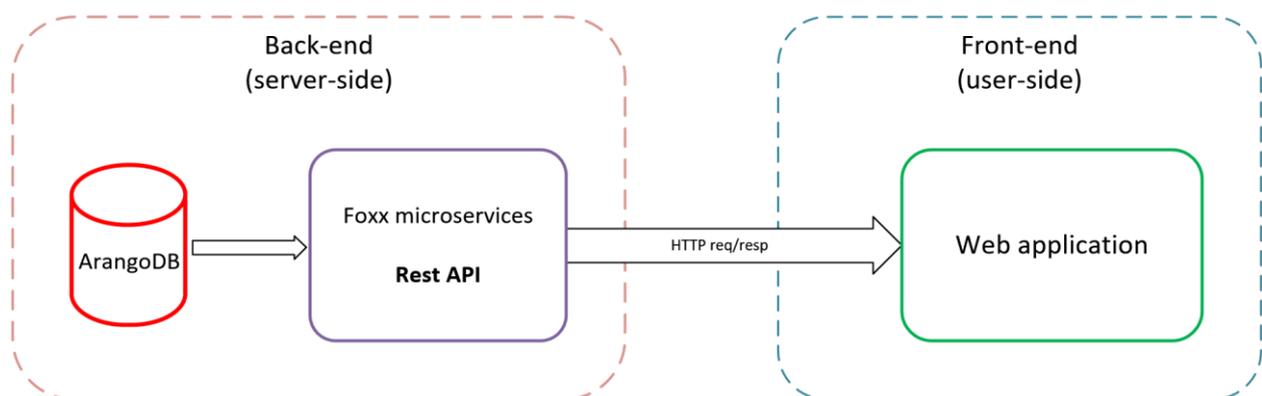


Figure 6. Diagram of the IT architecture of the SCV.

4.1. Force-directed Layout

Force-directed graph drawing is series of layout algorithms that iteratively computes the positions of each node of a graph by simulating an attractive force between two linked nodes, as well as a repulsive force between other nodes. The algorithm takes into account the relationship between nodes (as category), sizes of the nodes, the centrality degree, gravity, friction, edge weight as well as other factors as the sum of the forces acting on each node by all other nodes, overlapping avoidance or the dimension of the graph. The result is an intuitive and appealing visual layout that mimics physical forces by pushing nodes apart and pulling connected nodes together¹⁹.

The D3.js Force-directed graph layout²⁰ using velocity Verlet²¹ integration library was chosen for employing a highly customizable force-directed engine that enabled the design of a specialized visual layout for the Supply Chain Viewer: the four category of nodes (clusters) are arranged in concentric circles starting from inner material node (or nodes) cluster through the outermost circle of sectors nodes (Figure 7). This layout model – resulting from a number experimentation with different algorithms and different settings -

¹⁸ Single-page application

¹⁹ Brath & Jonker, 2015

²⁰ <https://github.com/d3/d3-force>

²¹ https://en.wikipedia.org/wiki/Verlet_integration

was chosen to conveniently render the SCV graph on various user displays and for the best possible UX (user-experience).

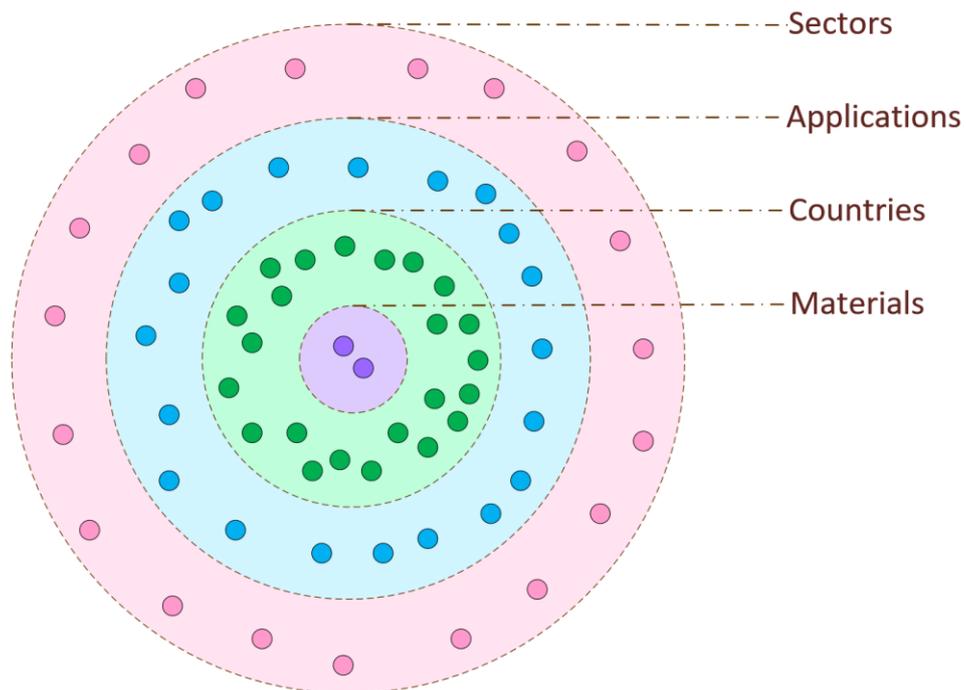


Figure 7. Visual layout for a single supply chain; the nodes are arranged concentrically, by cluster, using the Force-directed algorithm of D3.js.

A series of parameters or constraints are calculated to render the visual layout for a given SCV:

- Nodes' affinity to one of the four clusters for attraction-repulsion effects (nodes are attracting within the same cluster or repulsing for different clusters)
- Nodes' positioning – each node is displaced to its concentric circle (cluster)
- Nodes' sizes and minimum inter-distance for collision detection (prevents nodes from overlapping)
- Linkages - The link force pushes linked nodes together or apart according to the desired link distance.
- Number of iterations: programmatically computed using various parameters (number of nodes, links, sizes of nodes, context, GPU resources, screen size etc.) in order to render real-time animated simulations across various end-user devices.
- Other fine-graining and tuning parameters

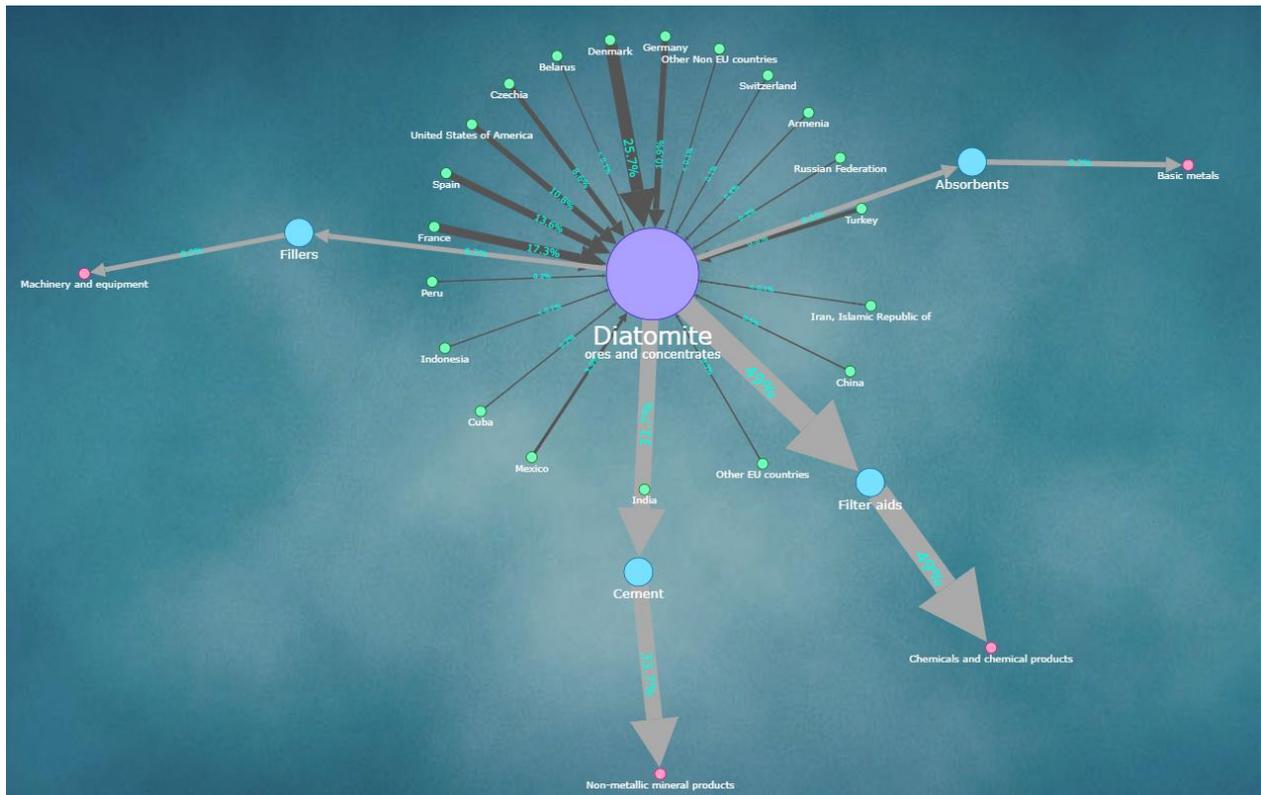


Figure 8. Actual example of the Diatomite SC. The concentric display of various node types is obvious.

In case of graphs with multiple nodes and edges (so multiple constraints) – as in the overlaid views or rich supply chains – the resulted layout can be unexpectedly complex and at first glance, it may appear chaotic (this is an intrinsic property of a force-directed algorithm dealing with great number of objects, relations and constraints).

4.2. The View Model and the Web Interface Design

The SCV application is logically and visually divided in four modules or views:

- The Material Supply Chain: displays a specific material supply chain including all available data and details
- Individual Node Views: displays a chosen node and its direct connected neighbors, regardless its material chain membership. This module is subsequently divided in three sub-views: Country, Application and Sector.
- Overlaid View: displays an overlay of two or three combined supply chains including associated details and data²².
- The Whole Supply Chain Network: displaying the whole network of nodes and links without data details; this module serves also as the entry point of the web page.

On the left side of the WEB UI (user interface), a menu panel presents dedicated buttons with dropdown sub-menus for each of the above-mentioned modules.

²² Suggested in Nuss & Ciuta, 2018

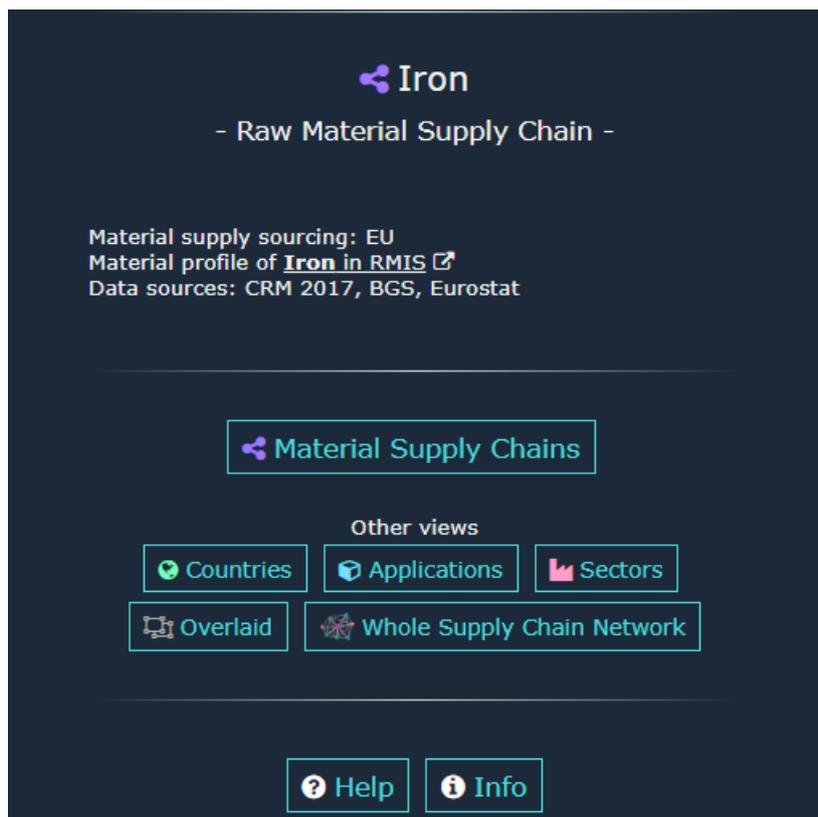


Figure 9. Left panel menu. In display, there is the Iron supply chain with details on material supply, data sources and the link to the Iron's material profile in the RMIS. The section below contains the buttons for launching other views. At the bottom, buttons Help and Info display subsequent information.

On the same panel, based on the selected view, additional information will be shown.

At the bottom of the panel there are two additional buttons **Help** and **Info** that launch dedicated windows with information on how to use the application and the latter with description of the scientific model and the underlying data.

4.2.1. The Material Supply Chain View

The links, representing the material flows, have thicknesses proportional to the share of the respective "link" (in terms of volumes/mass) in all "links/flows" of the same characteristics (flows of mass for the same raw material and category of interest). An arrow at the end of the "link" indicates the flow direction. Along the link, a text shows its corresponding share's value. The colors of these links are either dark grey for flows related to raw materials production, or light grey for flows related to raw materials use.

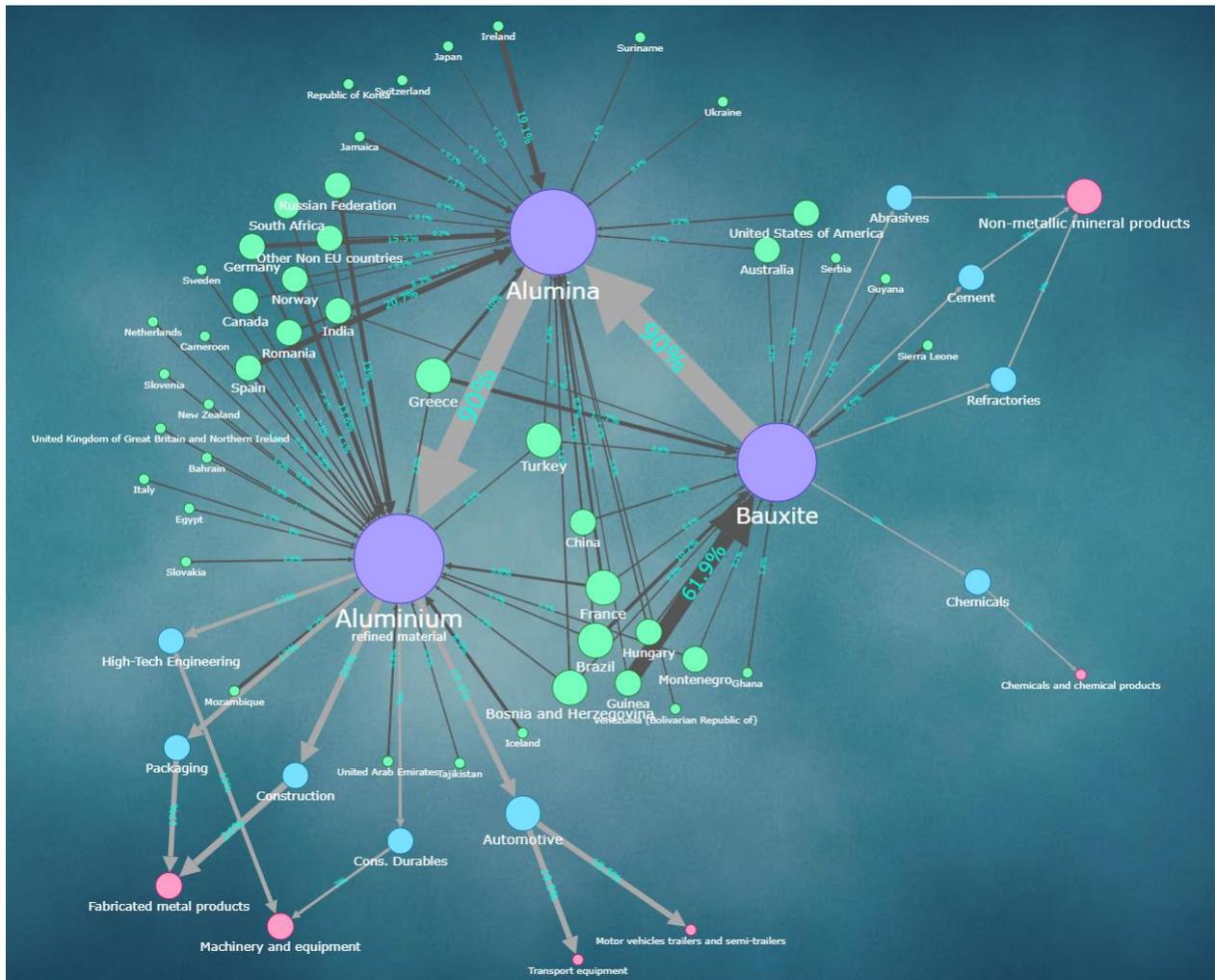


Figure 10. The Aluminium supply chain.

The size of a node is proportional to its “degree centrality” in the current graph view. In graph theory²³, the number of incident links upon a node gives the degree centrality. From the perspective of a material supply chain, the degree centrality, and so the node size, represents the importance of the node within the supply chain and can give a measure of the impact (chain disruption) in case of removal of a certain “important” node²⁴.

²³ Deo N., 2016

²⁴ Nuss & Ciuta, 2018

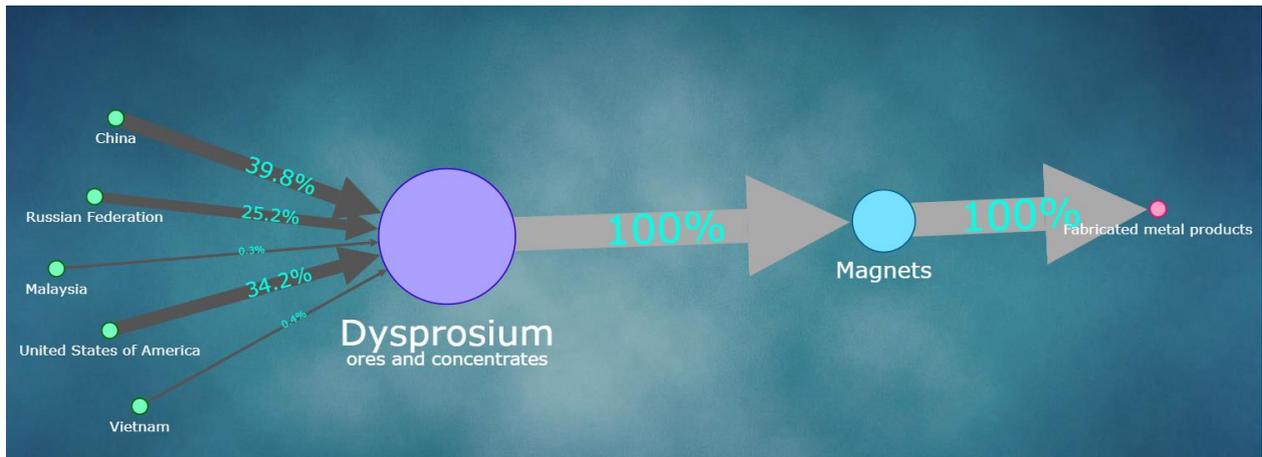


Figure 11. A simpler supply chain: Dysprosium with one product application, magnets.

From the perspective of a single material node, the sum of country supply shares equals 100%. The countries can produce multiple materials and the shares reported always equal 100% for a single material²⁵. The country-to-material supply shares are representing the EU-28 supply (EU imports + domestic production) for most of the supply chains. On the other hand, where EU data were not available, the shares refer to the global production. This aspect is specified on the left side panel for each supply chain. Also on the left side panel, the user will find external hyper-links to the corresponding country and material profiles in RMIS, when available.

Subsequently, the links from material products to product applications represent the shares of materials "used in" different product applications. In this case, the underlying data come exclusively from the CRM 2017 data set provides.

Finally, and similarly to the material to application flow links, the links from product applications to economic sectors represent the flows corresponding the use of product (shares) in different NACE-2 economic sectors.

The size of each node is proportional to the degree of the node (number of directly connected neighbors).

²⁵ Ibid.

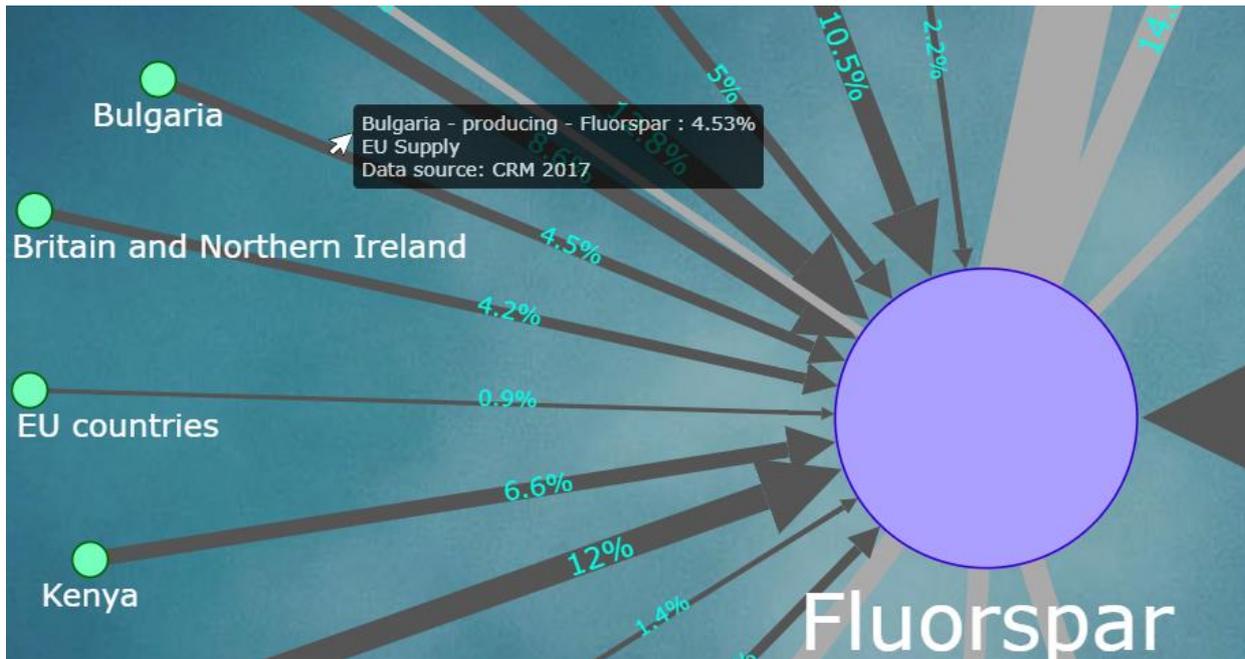


Figure 12. Zoom on a link detail: Bulgaria is producing fluorspar as 4,53% of the EU supply according to CRM 2017.

The thickness of the links is proportional to the share value inside the supply chain. The share values are shown on the links.

On the left side panel are shown the sources of data and a link to the RMIS material profile, if available.

User interactions: Double click or double tap on a node to display only its neighbors (directly connected nodes) and hide the other part of the network. Double click or tap on the background to restore the entire network view.

Double click or double tap on a link to display additional information on the specific flow between the connecting nodes, such as data source, values in percent, flow type.

4.2.2. The Individual Node Views

The individual node views section contains three sub-modules (Countries, Applications, Sectors) that present a view to the whole supply chain network from the perspective of singular country, application or sector node, highlighting the interlinkages among different raw materials supplies or uses, but does not look at any material supply chain individually. Instead, each view includes the supply chain membership on the links. Each view shows the chosen node and the nodes directly connected to it. For instance, by choosing Country view for Spain, the node "Spain" is displayed, as well as all the raw materials' products that Spain is producing and the links/flows that are connecting them, for all the supply chains that Spain is part of. On the left side panel, a list is available with the involved supply chains (direct hyper-links on them) for the selected node view.

4.2.2.1. Country Nodes

It shows the directly connected material nodes in all the supply chains that the selected country is part of.

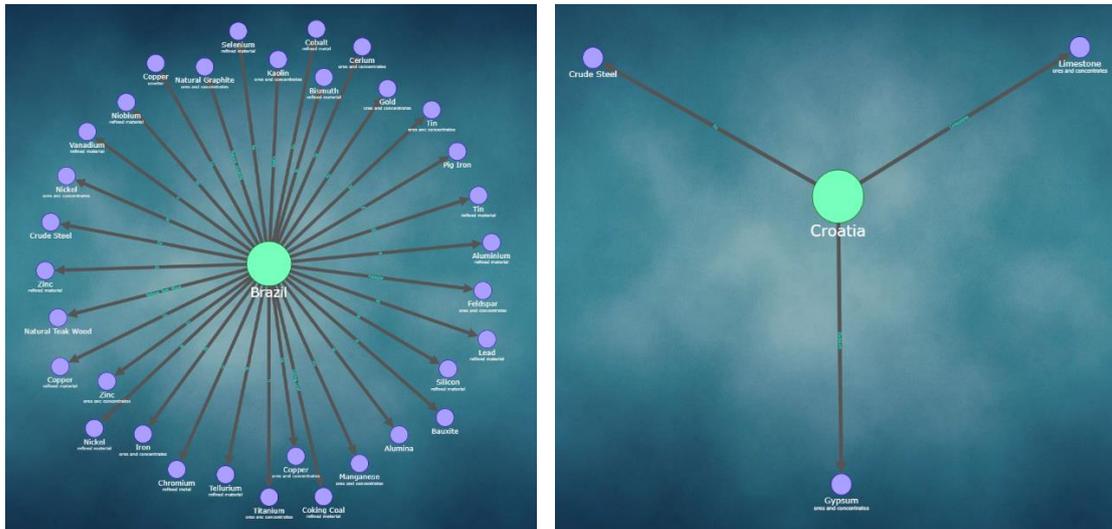


Figure 13. Brazil (left) and Croatia (right) – individual node views. One can assess the relative economic importance of a supplying country given the number of connections.

The size of the nodes is fixed as well as the position of the country node. On each link there is indicated the SC membership.

On the left panel are listed the links to the supply chains that the country is part of. If available, a link to the country profile in the RMIS website will be displayed.

User interaction: Double click or double tap on a material node to redirect to its associated supply chain.

4.2.2.2. Application Nodes

It shows the directly connected materials and sectors in all the supply chains that the selected application is part of.

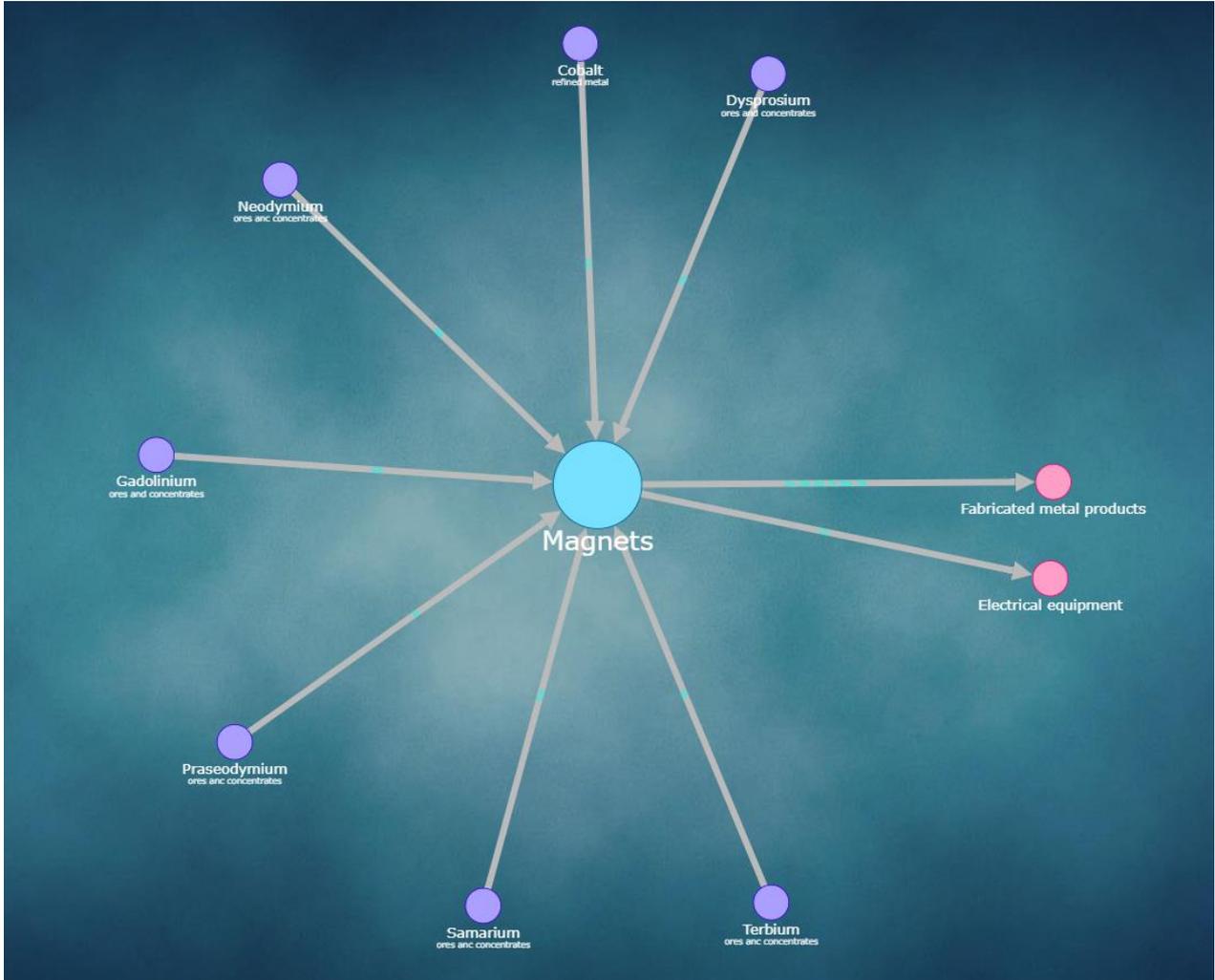


Figure 14. Application view for Magnets: Several rare earth metals and cobalt are used to produce magnets which are further used in the economic sectors of Electrical equipment and Fabricated metal products.

The size of the nodes is fixed as well as the position of the application node, in the center of the view. On each link there is indicated the SC membership.

On the left panel are listed the links to the supply chains that the application is part of.

User interaction: Double click or double tap on a material node or on a section node to redirect to its associated material supply chain or section view.

4.2.2.3. Sector Nodes

It shows the directly connected applications in all the supply chains that the selected sector is part of.

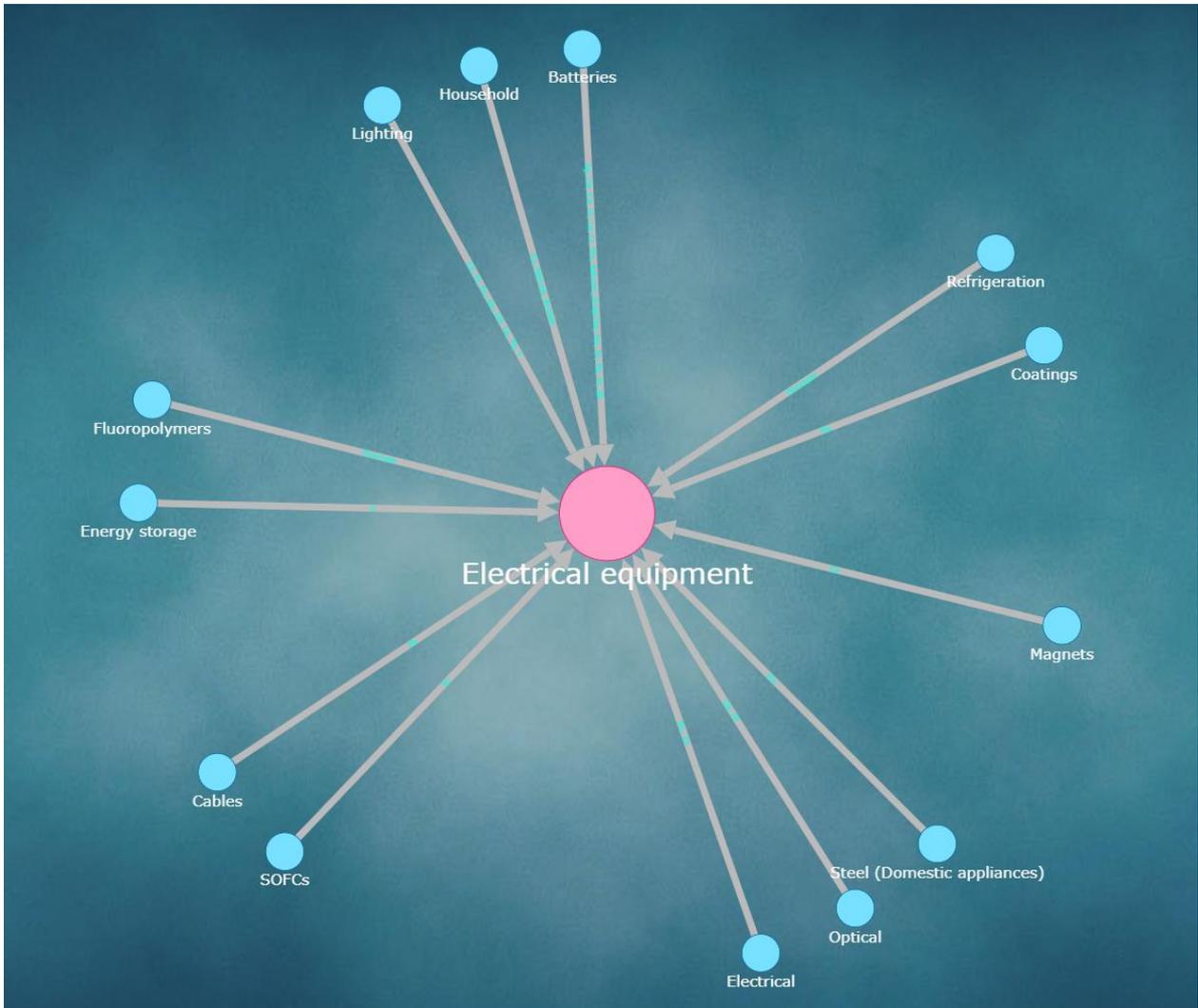


Figure 15. The Electrical equipment sector and incoming flows from various product applications.

The size of the nodes is fixed as well as the position of the sector node in the center. On each link there is indicated the SC membership.

On the left panel are listed the links to the supply chains that the sector is part of.

User interaction: Double click or double tap on an application node to redirect to its associated application view.

4.2.3. Overlaid View

The Overlaid view provides interconnection information among combined multiple supply chains. It can help to highlight the fact that materials are interlinked at various stages of their supply chain and that certain countries, materials, products, and sectors might be of greater importance for a defined set of materials, simply because of their increased interlinkage in the network, or large share in contributing to material flows²⁶. The nodes that are part of several chains in the overlaid view are highlighted with a black annular stroke. If two directly connected nodes are both part of more than one chain, the connecting link (that is consequently part of these chains) displays the supply chains associated with, and the corresponding shares. Additionally, on the left side panel, the application displays details on how the selected chains are interconnected, and a list with the interconnected nodes.

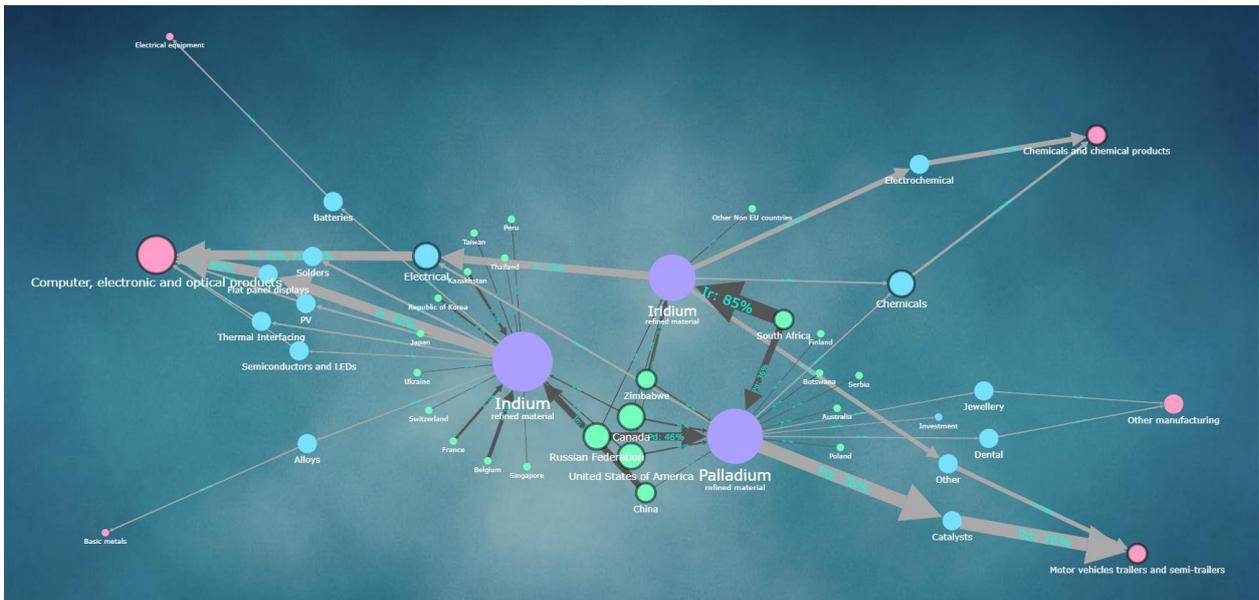


Figure 16. Overlaid view for Indium, Palladium and Iridium; note that all these three materials have a final use in the Computers, electronic and optical products sector.

The size of each node is proportional to the degree of the node (number of directly connected neighbors).

The thickness of the links is proportional to the weight of the selected supply chains. The share values are shown on the links along with the supply chain membership.

The interconnected nodes (shared by several of the selected chains) have a black stroke around them

On the left side panel is displayed information about interconnections of the selected chains: the interconnection level (all, two or none) and the common nodes, if any.

User interactions: Double click or double tap on a node will display its neighbors (directly connected nodes) and hide the other part of the network. Double click or tap on the background to restore the entire network view.

²⁶ As described in Nuss & Ciuta, 2018

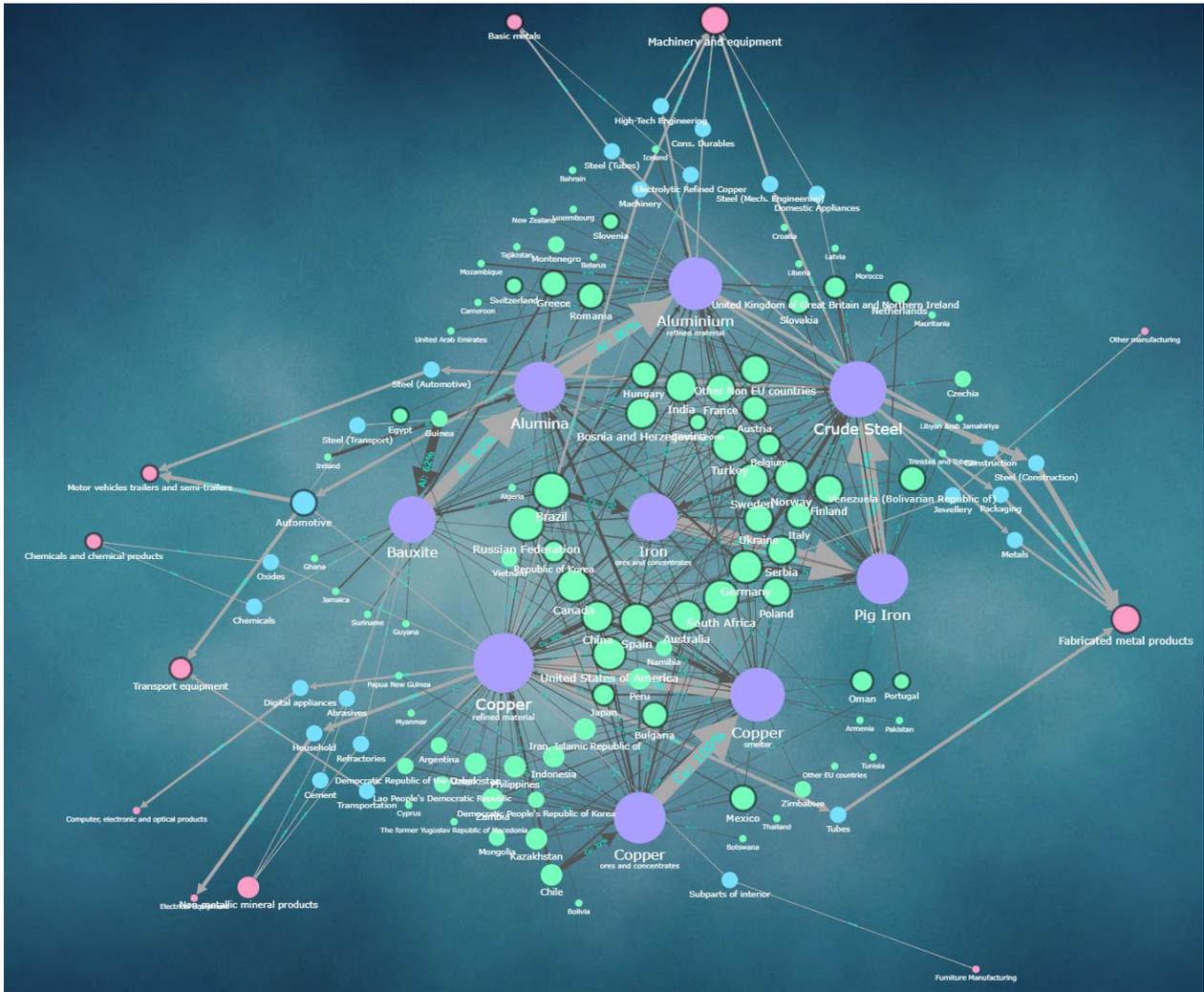


Figure 17. The rendered view can grow very complex in case of overlaying several heavy supply chains as Iron, Aluminium and Copper.

Given the variable computing performance on diverse end-users' devices and web browsers, only two or three supply chains are available to be selected at once and combined for showing an overlaid view²⁷.

²⁷ Displaying multiple large chains combined, such as Iron, Aluminium, Lead, Nickel, Copper, Zinc can have a big impact on the browser performance. As a result, and depending on the end user's computer resources, the view could run very slowly or even freeze the web browser.

4.2.4. The Whole Supply Chain Network

The Whole Supply Chain Network view serves as the main entry point of the application and visualizes the entire graph with all its members: countries, materials, end-use applications, and sectors involved in raw material supply chains that are shown as nodes and the relationships among them as links (edges) among the nodes. The degree centrality is applied as nodes' sizes to visualize the interconnectedness of each supply chain actor (node) in the raw materials network. Increasing node size indicates more interconnected nodes ("key players") in the production and use of raw materials captured by the Commission's CRM 2017 data set. The view can be interactively used to directly jump to a material supply chain view or individual node view. As an option, a secondary or *Alternate view* (upper left button on the Web UI) is provided in order to show the same content arranged in four concentric clusters (countries, materials, applications and sectors).

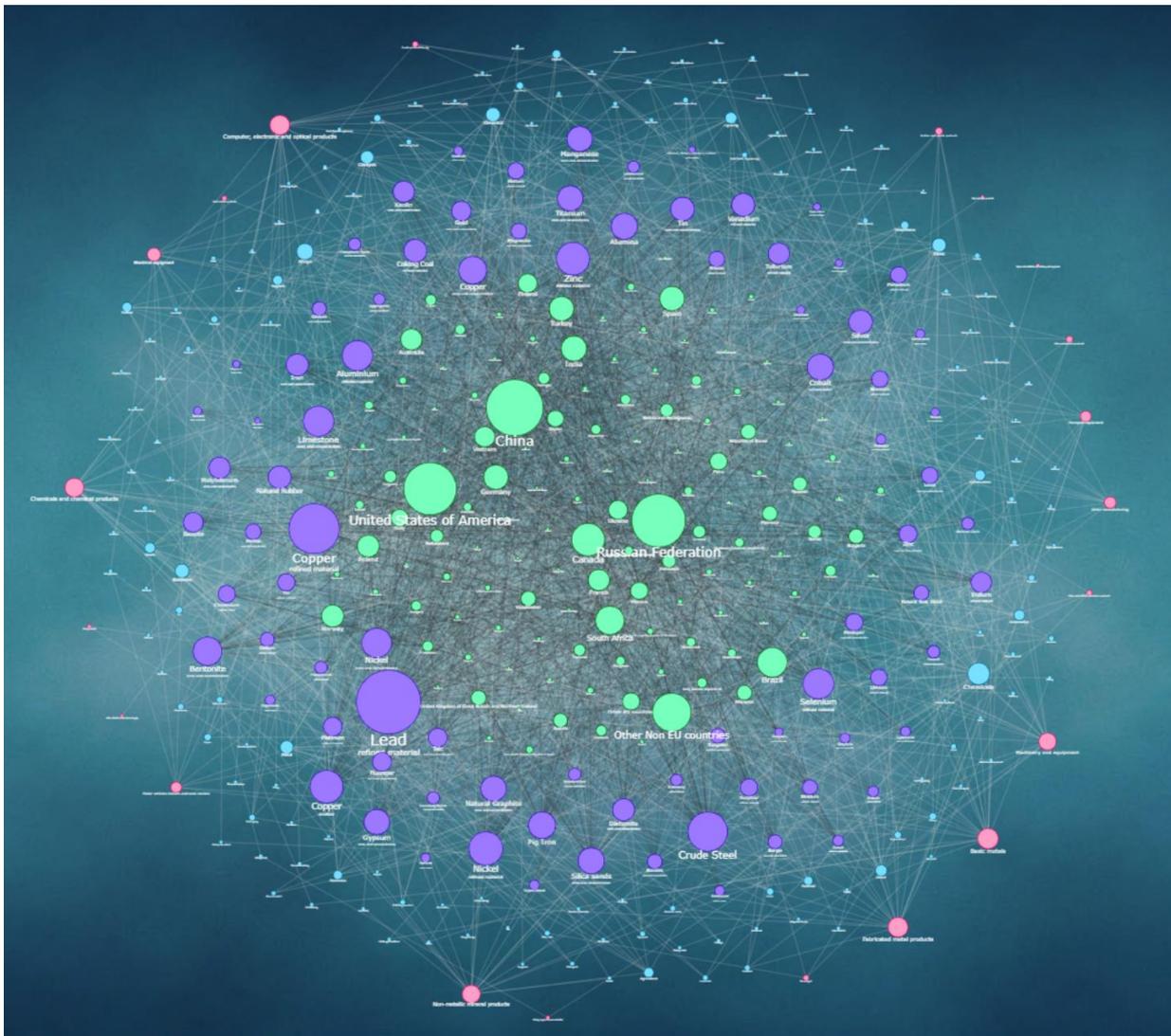


Figure 18. The Whole Supply Chain Network – concentric layout. This view is the main entry-point of the SCV application.

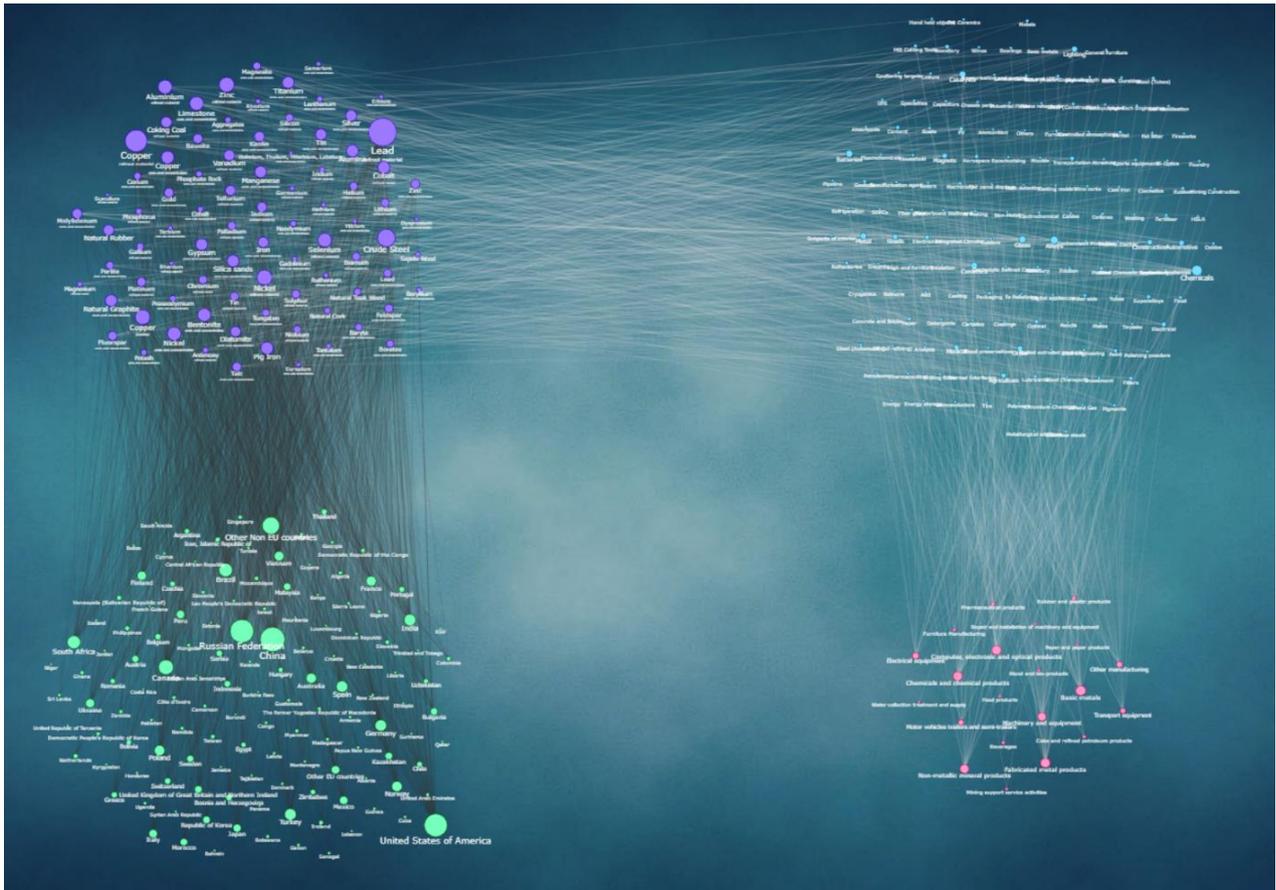


Figure 19. The Whole Supply Chain Network – alternate clustered layout.

This view is the SCV application's entry point and landing page. It displays the entire supply chain network without data details on edges.

User interaction: Double click or double tap (using tablet or phone) on a node will redirect to the corresponding view, a supply chain for material nodes or an item view for the other types of nodes.

4.2.5. General Considerations for All Views

The links color is either dark grey \longrightarrow for *producing* or light grey \longrightarrow for *used in*.

The nodes color codes: country - **green**, material - **violet**, application - **blue**, sector - **red**.

Use the mouse wheel or touchpad zoom to zoom in or out.

Mouse pick and drag a node to move it to the desired position.

Click the Refresh button in the upper right side of the screen to re-render the current view.

5. Conclusions

The SCV application is currently active on the EC's RMIS platform, in the *Industrial Value Chains & Material Flows* module, directly available at <http://rmis.jrc.ec.europa.eu/apps/scv>.

The main messages coming out from the description of the IT tool behind the concept of SCV are:

1. The SCV represents an *IT tool designed to show flows of raw materials along their supply chains in an interactive and visually attractive manner*; the format chosen is based on "graph" visual representation.
2. The originality of this IT application design consists in using a *dedicated graph database* solution for managing the underlying datasets of raw materials data. Graphs databases are useful to store elements that can easily adapt to dynamic business needs. They are fit for managing very large datasets where *relationships* (between nodes of the graph, therefore between potentially different types of categories of interest) *have priority against the individual data points* (nodes representing types of categories of interest) in terms of management of the entire information. In simple terms, the information concerning flows is the concept behind organizing the entire knowledge. The graph-type database organization also allows for queries to traverse very large numbers of nodes per time unit (native property of graph databases: *index-free adjacency*²⁸).
3. The IS solution (IT application) chosen for implementing the IT infrastructure of the SCV and for searching the data and information supporting the SCV is a dedicated graph database engine, ArangoDB, part of the NoSQL family.
4. The web application allows for searching and visualizing four types of categories of interest along the supply chain of a certain raw material: other raw materials involved along the supply chain; sectors (industries) which are intensively using the specific raw material; countries that are involved in the supply chain, either as main supplier or as main consumer; end-use applications that are technologically dependent on the specific raw material.

There are two immediate further developments, which can enhance in the future the scope and area of coverage for this IT application in the context of viewing supply chains of a given raw material or value chains of products along their supply chains:

- A. The SCV can be further extended to allow for identifying connections between nodes from opposite clusters; e.g. from a country node (Argentina) to a sector node (Chemicals) the tool could isolate/extract/visualize the material flows that connect these two end nodes; these flows can be parts of multiple supply chains (associated to several raw materials that contain the same two different-category nodes in their supply chains). Technically, these can be computed with dedicated *shortest path* algorithms such as Warshall-Floyd and Dijkstra (described in graph theory²⁹)

²⁸ Robinson I., 2015

²⁹ Deo N., 2016

- B. The information flows can be easily enlarged to cover not only "mass/volume" type of flows along the supply chain/value chain, but also flows expressed in value terms. Such an expansion of the knowledge base will allow in the future to present homogenous flows along the supply chain, increasing the consistency of the information between types of categories of interest. At this moment, the percentage approach (shares) is the unique possibility of showing linkages, as the basic information on various types of nodes (sector production, raw material inputs, country imports or exports, end-use production) is expressed in heterogeneous units of measure, although all having a volume (mass) equivalent; quite often, the mass equivalent used for the criticality assessment contains "expert judgments" or "transformation coefficients" based on available information and not on exhaustive information. The value term expression for flows may reduce the inherent error associated to the use of any expert-assessment by switching to the universal "*unitaire*".

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7. Abbreviations and Definitions

API - application program interface; in the context of computer programming, represents a set of routines, protocols, and tools that specifies how software components are interacting.

BGS – British Geological Survey

CRM – Critical Raw Materials

D3.js – open source JavaScript library for producing dynamic, interactive data visualizations in web browsers

DFS - Depth-first search; an algorithm for traversing or searching tree or graph data structures.

EC – European Commission

GPU – graphics processing unit / video card

HTTP methods (PUT, GET, POST etc.) – defines a series of request-response methods to enable communications between clients and servers

IS – information system

JSON - JavaScript Object Notation; an open-source format for storing and transferring data

NACE - "*Nomenclature statistique des Activités économiques dans la Communauté Européenne*" - Statistical Classification of Economic Activities in the European Community

NoSQL – “not only SQL”; an alternative to traditional relational databases (in which data is placed in tables and data schema is carefully designed before the database is built). NoSQL is any schema-free non-relational database.

REST/RESTfull - Representational State Transfer; an architectural style for developing web services.

RMIS - The European Commission's Raw Materials Information System

SCV – Supply Chain Viewer

SPA – single-page application; a type of web “application” that interacts with the user by dynamically rewriting the current page rather than loading entire new pages from a server.

UX – User experience refers to a person's perceptions and attitudes about interacting with a particular product, system or service. It assesses its utility, usability, accessibility, aesthetics and subjective value.

Web UI – Web User Interface; the way through which a user interacts with a web application.

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