## Tab. S1. Abbreviation of participating countries and countries in aluminum resource trade.

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Country ISO** | **Country** | **Country ISO** | **Country** | **Country ISO** | **Country** | **Country ISO** |
| Afghanistan | AFG | Cote d'Ivoire | CIV | Lao People's Dem. Rep. | LAO | Saint Helena | SHN |
| Albania | ALB | Dem. People's Rep. of Korea | PRK | Latvia | LVA | Saint Kitts and Nevis | KNA |
| Algeria | DZA | Dem. Rep. of the Congo | COD | Lebanon | LBN | Saint Lucia | LCA |
| American Samoa | ASM | Denmark | DNK | Lesotho | LSO | Saint Maarten | SXM |
| Andorra | AND | Djibouti | DJI | Liberia | LBR | Saint Pierre and Miquelon | SPM |
| Angola | AGO | Dominica | DMA | Libya | LBY | Saint Vincent and the Grenadines | VCT |
| Antigua and Barbuda | ATG | Dominican Rep. | DOM | Lithuania | LTU | Samoa | WSM |
| Argentina | ARG | Ecuador | ECU | Luxembourg | LUX | Sao Tome and Principe | STP |
| Armenia | ARM | Egypt | EGY | Madagascar | MDG | Saudi Arabia | SAU |
| Aruba | ABW | El Salvador | SLV | Malawi | MWI | Senegal | SEN |
| Australia | AUS | Equatorial Guinea | GNQ | Malaysia | MYS | Serbia | SRB |
| Austria | AUT | Eritrea | ERI | Maldives | MDV | Seychelles | SYC |
| Azerbaijan | AZE | Estonia | EST | Mali | MLI | Sierra Leone | SLE |
| Bahamas | BHS | Eswatini | SWZ | Malta | MLT | Singapore | SGP |
| Bahrain | BHR | Ethiopia | ETH | Marshall Isds | MHL | Slovakia | SVK |
| Bangladesh | BGD | Faeroe Isds | FRO | Mauritania | MRT | Slovenia | SVN |
| Barbados | BRB | Fiji | FJI | Mauritius | MUS | Solomon Isds | SLB |
| Belarus | BLR | Finland | FIN | Mexico | MEX | Somalia | SOM |
| Belgium | BEL | France | FRA | Mongolia | MNG | South Africa | ZAF |
| Belize | BLZ | French Polynesia | PYF | Montenegro | MNE | South Sudan | SSD |
| Benin | BEN | FS Micronesia | FSM | Morocco | MAR | Spain | ESP |
| Bermuda | BMU | Gabon | GAB | Mozambique | MOZ | Sri Lanka | LKA |
| Bhutan | BTN | Gambia | GMB | Myanmar | MMR | State of Palestine | PSE |
| Bolivia (Plurinational State of) | BOL | Georgia | GEO | N. Mariana Isds | MNP | Sudan | SDN |
| Bosnia Herzegovina | BIH | Germany | DEU | Namibia | NAM | Suriname | SUR |
| Botswana | BWA | Ghana | GHA | Nauru | NRU | Sweden | SWE |
| Br. Indian Ocean Terr. | IOT | Gibraltar | GIB | Nepal | NPL | Switzerland | CHE |
| Br. Virgin Isds | VGB | Greece | GRC | Netherlands | NLD | Syria | SYR |
| Brazil | BRA | Greenland | GRL | New Caledonia | NCL | Tajikistan | TJK |
| Brunei Darussalam | BRN | Grenada | GRD | New Zealand | NZL | Thailand | THA |
| Bulgaria | BGR | Guam | GUM | Nicaragua | NIC | Timor-Leste | TLS |
| Burkina Faso | BFA | Guatemala | GTM | Niger | NER | Togo | TGO |
| Burundi | BDI | Guinea | GIN | Nigeria | NGA | Tonga | TON |
| Cabo Verde | CPV | Guyana | GUY | Norfolk Isds | NFK | Trinidad and Tobago | TTO |
| Cambodia | KHM | Haiti | HTI | North Macedonia | MKD | Tunisia | TUN |
| Cameroon | CMR | Honduras | HND | Norway | NOR | Turkey | TUR |
| Canada | CAN | Hungary | HUN | Oman | OMN | Turkmenistan | TKM |
| Cayman Isds | CYM | Iceland | ISL | Pakistan | PAK | Turks and Caicos Isds | TCA |
| Chad | TCD | India | IND | Palau | PLW | Uganda | UGA |
| Chile | CHL | Indonesia | IDN | Panama | PAN | Ukraine | UKR |
| China | CHN | Iran | IRN | Papua New Guinea | PNG | United Arab Emirates | ARE |
| China, Hong Kong SAR | HKG | Iraq | IRQ | Paraguay | PRY | United Kingdom | GBR |
| China, Macao SAR | MAC | Ireland | IRL | Peru | PER | United Rep. of Tanzania | TZA |
| Christmas Isds | CXR | Israel | ISR | Philippines | PHL | United States Minor Outlying Islands | UMI |
| Colombia | COL | Italy | ITA | Poland | POL | Uruguay | URY |
| Comoros | COM | Jamaica | JAM | Portugal | PRT | USA | USA |
| Congo | COG | Japan | JPN | Qatar | QAT | Uzbekistan | UZB |
| Costa Rica | CRI | Jordan | JOR | Rep. of Korea | KOR | Vanuatu | VUT |
| Croatia | HRV | Kazakhstan | KAZ | Rep. of Moldova | MDA | Venezuela | VEN |
| Cuba | CUB | Kenya | KEN | Romania | ROU | Viet Nam | VNM |
| Curacao | CUW | Kiribati | KIR | Russian Federation | RUS | Yemen | YEM |
| Cyprus | CYP | Kuwait | KWT | Rwanda | RWA | Zambia | ZMB |
| Czechia | CZE | Kyrgyzstan | KGZ | Saint Barthelemy | BLM | Zimbabwe | ZWE |

# 2. Commonly used calculation indicators in complex networks

(1) Degree and cumulative degree distribution

Degrees in complex networks represent trade relationships between nodes. Node degree ki means the number of a country's trading partners (region). The higher the degree is, the wider the direct influence of node countries is, while the cumulative degree distribution is the probability distribution of these countries in the network. The calculation are shown as formula (1-3).

$$\begin{array}{c}K\_{i}=\sum\_{j=1}^{N}m\_{ij}=K\_{i}^{in}+K\_{i}^{out}\#\left(1\right)\end{array}$$

$$\begin{array}{c}<k\geq \frac{\sum\_{j=1}^{N}K\_{i} }{N}\#\left(2\right)\end{array}$$

$$\begin{array}{c} CP\left(k\right)=\sum\_{K\geq k}^{}p\left(K\right)\#\left(3\right)\end{array}$$

Where, $k\_{i}$ is the degree of trading countries, $<k>$ represents the average degree in the network, $m$ represents the number of countries in the network, and $CP(k)$ represents the cumulative degree distribution greater than node $K$. $p\left(k\right)=N\_{k}/N$ indicates the proportion of nodes whose medium value is $K$ on the network. $N\_{k}$ indicates the number of nodes with degree $K$.

(2) In-degree and out-degree of a node

The node degree can be divided into the number of import trade relations and export trade relations. With the increasing number of countries participating in trade, the ties between countries (regions) are also getting closer. The out-degree of node $i$ represents the number of trade partners for country $i$ to export aluminum, and the in-degree represents the number of trade partners for country $i$ to import aluminum. The in-degree and out-degree formulas are shown in formulas (4,5).

$$\begin{array}{c}K\_{i}^{out}\left(t\right)=\sum\_{j=1}^{N\left(t\right)}m\_{ij}(t)\#\left(4\right)\end{array}$$

$$\begin{array}{c}K\_{i}^{in}\left(t\right)=\sum\_{j=1}^{N\left(t\right)}m\_{ji}(t)\#\left(5\right)\end{array}$$

In the formula, N(t) is the total number of countries in the aluminum trade network in year $t$; $m\_{ij} $and$ m\_{ji}$ are the values of the adjacency matrix of the network.

(3) Incoming and outgoing strengths of nodes

In the trade network, the node strength represents the trade volume through the country, and the node strength in the directed network is divided into outgoing intensity and incoming intensity. The formula for calculating the power of node $i$ is shown in formula (6,7), where $wij$ is the weight from node$i$ to node $j$.

$$\begin{array}{c}Q\_{i}^{in}\left(t\right)=\sum\_{j=1}^{N\left(t\right)}W\_{ij}(t)\#\left(6\right)\end{array}$$

$$\begin{array}{c}Q\_{i}^{out}\left(t\right)=\sum\_{j=1}^{N\left(t\right)}W\_{ij}(t)\#\left(7\right)\end{array}$$

## 3. A detailed introduction to the Leiden algorithm

In complex network research, the degree of modularity is used to divide the community of participating countries in the network and to discuss its internal network structure. The greater the modularity, the stronger the stability of the community, the higher the degree of differentiation between countries, the more pronounced the small world phenomenon, and the lower the degree of trade globalization. On the contrary, the smaller the degree of modularity, the lower the stability, the less noticeable the differentiation of trade groups formed between countries, and the trade trend towards globalization.

Louvain algorithm is a method commonly used by scholars at this stage, which can efficiently and timely calculate the community division results of different networks. This paper uses the Leiden algorithm proposed by V. Traag et al. to divide the copper resource trade network into various stages to improve the accuracy of the division results. The algorithm flow is as follows.

(A) The first stage: assuming that each node in the complex network is an independent community, use the fast local movement algorithm to move the nodes to find the partition locally.

The Leiden algorithm initializes all nodes in the network into a queue and randomly adds nodes to it. Delete the first node from the queue head, add it to other communities, and judge whether the quality function can be improved. If so, move the node to that community. Add a new community that does not belong to this node to the tail of the queue. Add all neighbors that are not in the line to the bottom of the row. The node is continuously removed from the head of the queue, and the previous steps are repeated until the queue is empty. It is necessary to judge which community node i joins through the gain value ΔP of the modularity.

$$\begin{array}{c}∆P=\left[\left(\frac{\sum\_{}^{}in+k\_{m,in}}{2T}\right)-\left(\frac{\sum\_{}^{}tot+k\_{m}}{2T}\right)^{2}\right]-\left[\frac{\sum\_{}^{}in}{2T}-\left(\frac{\sum\_{}^{}tot}{2T}\right)^{2}-\left(\frac{k\_{m}}{2T}\right)^{2}\right]\\=\frac{1}{2T}\left(k\_{m,in}-\frac{\sum\_{}^{}totk\_{m}}{T}\right)\#\end{array}(8)$$

T is the number of edges in the network, and $\sum\_{}^{}in $in is the sum of the edge weights of the nodes where the community G is located. $k\_{m,in}$ is the sum of the edge weights of node m pointing to all nodes in community G. $\sum\_{}^{}tot $tot is the total weight of the edges pointing to all nodes in community G. $k\_{m}$ represents the sum of edge weights pointing to node m.

(B) The second stage is the refinement of the partition.

First, mark the communities identified in Phase 1, and determine the community location corresponding to each node; secondly, locally merge the nodes in the area. In this phase, the merge of different nodes is only performed in each community and only in the same community. Nodes within a community will only merge when two adjacent nodes within a community are sufficiently connected. After the refinement phase, the original trade network is refined into multiple districts.

(C) The third stage is network aggregation. Create an aggregated network based on refined partitions, use non-refinement cells to create initial sections for the aggregated network, and repeat the above operations until the community partition does not change.

Creating a local aggregation network makes it possible to have more space to identify high-quality partitions. In the community division, modularity is used to measure the result of the final community division. After one round of the iteration cycle, if the modularity P of the network does not change, stop the process; otherwise, iterate again until there is no change to obtain the community division result of the network. Modularity is calculated as follows:

$$\begin{array}{c}P=\frac{1}{2T}\sum\_{mn}^{}\left[A\_{mn}-\frac{k\_{m}k\_{n}}{2T}\right]β\left(D\_{m,}D\_{n}\right)\\=\frac{1}{2T}\left[\sum\_{mn}^{}A\_{mn}-\frac{\sum\_{m}^{}k\_{m}\sum\_{n}^{}k\_{n}}{2T}\right]β\left(D\_{m,}D\_{n}\right)=\sum\_{D}^{}\left[\frac{\sum\_{}^{}in}{2T}-\frac{\left(\sum\_{}^{}tot\right)^{2}}{2T}\right]\#\end{array}(9)$$

$$\begin{array}{c}β\left(G\_{m,}G\_{n}\right)=\left\{\begin{array}{c}1\#when m=m\\0 \#\#else\end{array}\right.\#\end{array}(10)$$

$A\_{mn}$ represents the weight of the edge between nodes m and n, $k\_{m}$ is the sum of the weights of the edges connected to node m, and $G\_{m}$ represents the community where node m is located. The $β\left(G\_{m,}G\_{n}\right)$ represents the category of different nodes. If node m and n are in the same community, the return value is 1. Otherwise, it is 0.