Evaluation of the Material Flow of Primary Aluminium – The Contribution of the ISAL Information System

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Abstract

In this paper the ISAL information system (Information System ALuminium) shall be introduced within its context. It forms the basis of the systems analysis which is performed in the framework of the Collaborative Research Centre (CRC 525) “A Resource-Orientated Analysis of Metallic Raw Material Flows” (SFB 2001). In the information system, data are organized and collected which serve the evaluation of the material flow of primary aluminium.

1. Some Issues of the Systems Analysis and the Information System

One of the aspects of the systems analysis is the evaluation of the material flow according to technology, time and geography. This aspect covers the following topics:

- With the help of time series, the shift of the regional distribution of the production of bauxite, alumina and primary aluminium is examined as well as the shift of the consumption of primary aluminium.
- For the status quo, on the basis of commercially available data, the operational data are aggregated and analysed concerning the various technologies and the regional differences in their application within the scope of process inputs and cost data.
- Socio-economic data and consumption data are applied to predict the consumption of primary aluminium in the future. The calculations are performed with a model considering various scenarios.
- Using the operational data, the different forecasts from the scenarios for the consumption of primary aluminium and some additional data, e.g. upgrading and investment cost within regions, future allocation of regional production, are calculated with the GLOBAL model. GLOBAL simulates a fully competitive
global primary aluminium market as an economic cost minimizing-model based on linear programming. On the basis of the scenarios, in a further step the model calculates greenhouse gas emissions for a base and a target year.

Developing such a system consisting of the information system and the two economic models requires the collaboration of engineers, economists and computer scientists.

In the following, we concentrate on the ISAL information system.

2. The Dimensions of the Information System and the Data Sources

According to the mission, the information system has the dimensions of time, geography and - when applicable - technology. The timescale is the year, the basis for geographical considerations is the country, usually aggregated to regions, technology is reflected in the process steps of the process chain with the different variants of the applied processes.

Integrated into the database is data from the various sources such as

- Time series about the production of bauxite, alumina, primary aluminium, secondary aluminium and the consumption figures mainly from Metallstatistik (MS – various years)
- Operational data about alumina and aluminium production sites from CRU, a commercial provider of business information (CRU 1996)
- Additional data from various sources usually adapted to the dimensions of time and geography.

The integration of data from different sources involves the difficulty of adapting the data to the different dimensions.

Along the timescale this is usually easy because most data sources use the year with 4 digits.

The geographical scale with names of countries – we consider more than 100 countries – usually requires some adaptations depending on the form of the acquired data. Coming from another relational database, an allocation table is generally sufficient, but when the source data is present in the form of spreadsheets in addition to a different naming convention usually different occurrences of names for the same country can be found. To allow aggregations on the countries these discrepancies must be removed. Part of the data model concerning the geographical dimension is shown in Figure 1.
On the right hand side our central table $G_{Countries}$ is shown with its attributes and some of the value tables which guarantee an identical spelling of the aggregation values. On the left hand side, two examples of applications are given. The upper one is the connection to the data of the World Bank, the lower one connects one table from CRU. The World Bank stores its data in a relational database and uses a country ID in its data. It resolves this ID in an allocation table which we expanded by an additional attribute to join the World Bank data to our geographical model. CRU delivers the data in spreadsheets, one spreadsheet for each site containing the country name. Here different spellings exist (e.g. United Kingdom, UK, U.K.) and each site must be checked and if necessary adapted to our naming rules. Our own country names are then assigned to several fixed aggregation possibilities like continents, OECD vs. Non-OECD countries, the income groups of the World Bank and – last but not least - the regions of GLOBAL. Additionally, there is an easy method to select distinct countries for special groupings.

Similar work arises for the adaptation of the expressions of the techniques.

### 3. The Structure of the Information System

The basic data of the time series follows the structure (data source, country, year, product, subject, number, unit, e.g. ‘Metal Statistics 1985-1995’, ‘Germany’, 1995, ‘Consumption’, ‘Primary Aluminium’, 1503900, ‘t’). This structure is advantageous because it treats all parameters the same and offers flexible evaluations along the dimensions time and geography. Additionally, it allows to store single data in a
structured way that it can be found easily (e.g. ‘Australia Now - Statistics’, ‘Australia’, 1995, ‘Employees’, ‘Bauxite’, 1792,-).

The socio-economic data is stored in a slightly different kind of time series because the adaptation of the title of a time series into the categories “subject” and “product” would be very difficult and not necessarily unique. Therefore, each data source leads to a small table system with the actual data stored in unique tables for each data source, e.g. WB-Timeseries, WB-Countries for the data of the World Bank. The basic table usually comprises country-number, time-series-number, year, value and some explanation tables. In the table where the country number is related to the country name two country names are given, the original name from the data source (if necessary, made unique) and our country name which then correlates with the possibilities of the geographic aggregation. The unit of the value is, depending on the data source, embedded in the title of the time series or is an extra field in the description table of the time series. For easy reconstruction of a time series, the titles are collected under about ten headings, each comprising several subheadings.

The operational data comprises capacity, production and technology of a site with extensive data about the process inputs, the cost of input material, energy, labour etc. This data is available for the alumina processing and the processing of primary aluminium. The data structure is kept similar to the original data and the original data is left untouched. So the data structure of aluminium smelters is one simple table. The adjustment of the data and first fundamental calculations, e.g. the conversion of local currency to US dollars, lead to additional description fields, which then form the basis of the evaluations. The structure of alumina processing is a small table system concerning process data, bauxite sources and prices, and for each internal process step the energy consumption according to the kind of used energy. Here the fundamental calculations lead to additional tables, e.g. about energy consumption.

The additional data round the picture off. If the data fits into the structure of the time series (data source, year, product, subject, number, unit) it is held there, as described above. If the data are bulkier they are held in additional structures.

4. ISAL Sample Evaluations

The evaluations of the information system are used in various directions. For general purposes, background data are asked for in various aggregations. Examples are

- The distribution of the production of bauxite, alumina and primary aluminium along the continents for selected years.

Figure 2 displays the graphics for bauxite and primary aluminium.
The growing importance of Asia, Africa and – especially in the case of bauxite – of Oceania is immediately apparent.

- Minima, maxima and weighted averages of process inputs according to the process step or their variants.

![Figure 1](image1.png)

**Figure 1**
The shift in production along the continents (Metal Statistics)

![Figure 2](image2.png)

**Figure 2**
Specific energy consumption for various electrolysis technologies (CRU 1996)
Figure 2 illustrates the frequency of the application of the various technologies (the numbers given) and the consumption of one of their main inputs, namely the energy consumption per ton of primary aluminium.

- A time series of the development of the GDP (Gross Domestic Product) for the regions of GLOBAL. The socio-economic data is used to predict the future demand for primary aluminium. An example is the regionalized GDP per capita, which must be calculated as the sum of GDPs of the countries in the region divided by the sum of the inhabitants of the countries in the region. The available user interfaces to existing databases do not offer such flexible aggregations.

- A very fundamental aspect for our project is the calculations for GLOBAL (Schwarz et al. 2000). GLOBAL depends on fixed regions because besides the variable data from the database it uses additional data (e.g. tariffs between countries or primary energy demand for the production of electricity to calculate the greenhouse gases) which are not based on flexible data sources and which would be very laborious to change. After the basic calculations, for each region and each variant of a process step the process input is aggregated, weighted by the production figures. For each region the prices are weighted by the consumption of the process input. Additional costs such as overhead costs are aggregated by the capacity figures.

Table 1 and Table 2 show excerpts from the data evaluation which serves as an input to GLOBAL.

<table>
<thead>
<tr>
<th>Region</th>
<th>Pot Type</th>
<th>kWh / t Al</th>
<th>t Alumina / t Al</th>
<th>kg AlF₃ / t Al</th>
<th>kg Cryolite / t Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>CWPB</td>
<td>13866</td>
<td>1.94</td>
<td>26</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>HSS/VSS</td>
<td>14600</td>
<td>1.94</td>
<td>50</td>
<td>33.21</td>
</tr>
<tr>
<td></td>
<td>SWPB</td>
<td>14570</td>
<td>1.94</td>
<td>34</td>
<td>16.05</td>
</tr>
<tr>
<td>Region 2</td>
<td>CWPB</td>
<td>15437</td>
<td>1.94</td>
<td>33</td>
<td>17.43</td>
</tr>
<tr>
<td></td>
<td>PFPB</td>
<td>13859</td>
<td>1.94</td>
<td>23</td>
<td>7.30</td>
</tr>
</tbody>
</table>

Table 1
Excerpt from the input to GLOBAL – Consumption (CRU 1996)
In Table 1 examples of the consumption data (electricity, alumina, aluminium fluoride and cryolite) are given. The aggregations for each region and each pot type are calculated by the formula (e.g. Alumina)

\[ \frac{\sum (\text{Alumina}(t/t \text{ Al}) \times \text{Production}(t \text{ Al}))}{\sum \text{Production} (t \text{ Al})}, \]

thus production weighted. In Table 2 the corresponding prices for the process inputs are given. The input prices do not depend on the technology therefore the aggregation is done per region only. On the other hand, consumption and prices may be dependent on each other. Therefore the prices are calculated by the formula (e.g. Alumina)

\[ \frac{\sum (\text{Price Alumina} ($/t \text{ Alumina}) \times \text{Alumina}(t/t \text{ Al}) \times \text{Production}(t \text{ Al}))}{\sum (\text{Alumina}(t/t \text{ Al}) \times \text{Production} (t \text{ Al})}, \]

thus consumption weighted.

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Region} & \text{Prices in US $ /} & \\
& \text{kWh} & \text{t Alumina} & \text{t AIF}_3 & \text{t Cryolite} \\
\hline
\text{Region 1} & 0.018 & 411 & 945 & 1081 \\
\text{Region 2} & 0.019 & 428 & 981 & 850 \\
\text{Region 3} & 0.022 & 405 & 1067 & 1050 \\
\text{Region 4} & 0.040 & 521 & 1024 & 914 \\
\hline
\end{array}
\]

Table 2
Excerpt from the input to GLOBAL – Prices (CRU 1996)

5. Conclusion
The ISAL information system is constructed to collect the relevant data sources and to adapt the data sources to our dimension units. As a result ISAL has become an integral part of the systems analysis of the material flow of primary aluminium. It delivers various background data and feeds the models with their input data, especially when this data consists of aggregations on complex data structures which can be best handled on the basis of a relational database.
6. References

CRU (1996): CRU International, Alumina Refining Costs, Primary Aluminium Smelting Costs

MS (various years): World Bureau of Metal Statistics, Metallstatistik


WB (1999): The World Bank, World Development Indicators 1999 (CD-ROM)