rare earth; information system; environment; resources

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RARE EARTH ELEMENTS IN RAILWAY INFRASTRUCTURE – POTENTIALS FOR AN INFORMATION SYSTEM AS A TOOL FOR OPERATORS AND OTHER STAKEHOLDERS

Summary. Rare earth elements are used for specific products and components in the railway infrastructure. The application of rare earths in this sector includes fields such as command and control technology, power supply and telecommunication. The demand for these items continues to rise, whereas the natural supply remains limited. This can lead to escalation of prices and can advance to natural resource conflicts. In addition, the degradation of these elements is often carried out under conditions which can be life threatening or harmful. This contribution presents a new systematic approach for analysis of rare earths in the field of railway infrastructure. This fills the gap of studies in the sector of railway infrastructure regarding identification, substitution, recycling and innovation to replace these elements, which are well performed in other fields of technology and industry. This paper first provides the basics of rare earths and analyses their relevance in the sector. Furthermore, proposes a basic conceptual design of an information system for evaluation and analysis of these elements. This was done by contextual analysis where the relevant stakeholders such as infrastructure operators or industry, were identified. The analysis included the demand of the stakeholder for such an information system. Thus, the design and the architecture of an information system was specified. The system should provide a tool for operators of rail infrastructures to get a systematic overview on the use of rare earths elements and for strategic decisions, e.g. substitution by other elements, cooperation with suppliers for alternatives, including consideration of the Life Cycle Cost.

PIERWIASTKI RZADKIE W INFRASTRUKTURY KOLEJOWEJ – POTENCJAŁ DLA SYSTEMU INFORMACYJNEGO JAKO NARZĘDZIE DLA OPERATORÓW I INNYCH ZAINTERESOWANYCH STRON

Streszczenie. Pierwiastki rzadkie są wykorzystywane do konkretnych produktów i komponentów infrastruktury kolejowej. Zastosowanie pierwiastków rzadkich w tym sektorze zawiera się w obszarach, takich jak: dowodzenie i techniki sterowania, zasilanie oraz telekomunikacja. Popyt na pierwiastki rzadkie nadal rośnie, podczas gdy naturalna podaż pozostaje ograniczona. Może to prowadzić do eskalacji cen, i przekształcić się w konflikty o zasoby naturalne. Ponadto, degradacja takich elementów często przeprowadzana jest w warunkach, które mogą stanowić zagrożenie dla życia. Artykuł pokazuje nowe podejście do analizy systematycznej pierwiastków rzadkich w obszarze infrastruktury kolejowej. Analiza wypełnia lukę w badaniach w sektorze infrastruktury kolejowej w zakresie identyfikacji, substytucji, recyklingu i innowacji elementów, które są dobrze opisane w innych dziedzinach techniki i przemysłu. Praca jako pierwsza dostarcza podstaw wiedzy obejmującej pierwiastki rzadkie i analizuje ich znaczenie w sektorze kolejowym. Ponadto, proponuje podstawowy projekt koncepcyjny systemu informacji do oceny i analizy tych elementów. Został on opracowany na podstawie analizy kontekstowej, w którym brały udział zainteresowane strony, takie jak operatorzy infrastruktury i przemysłu. W analizie uwzględniono zapotrzebowanie udziałowcy dla takiego systemu informatycznego. Zarówno projektowanie, jak i architektura systemu informacyjnego zostały określone. System powinien być narzędziem dla operatorów infrastruktury kolejowej tak, aby móc uzyskiwać systematyczny przegląd wykorzystania pierwiastków rzadkich i podejmować strategiczne decyzje, przykładowo dotyczące zastąpienia ich przez inne elementy, współpracy z dostawcami dla alternatyw, uwzględniania kosztu cyklu życia.

1. INTRODUCTION

Rare earth elements belong to a group of 17 chemical elements in the periodic table which is composed of scandium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, yttrium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Because of their geochemical properties, these elements have a common characteristic that they are typically found dispersed and are not concentrated in exploitable natural deposits; therefore, they are viable to mine economically. The natural abundance of rare earths depends on their atomic size, the heavier the metals, they become scarce [13]. Rare earths are being used more and more in green technologies, such as wind turbines, solar technologies, fluorescent light and white LEDs, electric vehicles among others. Even though their application in low carbon technologies are increasing, there is a growing concern about the social and environmental negative impacts related to their extraction, processing and wastes. For instance, the guardian [15] reported that, in China, the ore of rare earths is often laced with radioactive materials, and processing one ton of rare earths produces 2000 tons of toxic wastes as well as several tons of waste water. Furthermore, recycling of RE is still quite limited and was calculated in 2011 to be around 1 percent of supply [12]. These problems have long been discussed and assessed from different perspectives, both in the scientific community and in politics. Several research endeavours attempt to contribute in the alleviation of the aforementioned problems related to the rare earth elements. Studies examined individual elements, assessed their applications and developed solutions on possible substitution of these elements or recommend options for efficient recycling processes and their implementations. On the other hand investigations are carried out to identify the affected products, predict the future demand, and the possible solutions such as substitution, recycling and innovation [1, 9-11] among others. However to estimate the impact of these solutions, Binnemans, [13] recommends the global inventory and lifecycle analysis of the different rare earths in use and study of the lifespan of devices containing rare earths. Other sources also recommend improvement through better information accessibility. In this regard, Zepf [14] concludes, the substitution of rare earths should be tried. To achieve that, it is necessary to generate an exact data, however currently only a limited amount of information is available on the application of rare earths. Strategies are already developed for this issue; for instance, the US Department of Energy in the year 2011 published a strategy paper called "Critical Material Strategy". This strategy paper incorporates short term (up to 5 years) and long-term (5-10 years) plans for many fields, such as wind energy, electric vehicles, photovoltaic among others [5]. Besides, general strategies and investigations are found at European level „Materials Roadmap" of the SETI (Strategic Energy technologies Information System) where for certain area own road maps are generated, for example for wind energy, bioenergy, hydrogen and fuel cell particle [19]. Nevertheless, there is no road map for infrastructures, especially for railway infrastructures. Material information system derived from the road map by packaging information from the road map still does not include infrastructure.

Besides the actual problem issues of rare earths in relation to for example environmental concerns their economic relevance and promotion (funding) for the future are being discussed. In keeping with the current status of utilization progress, rare earth can in few years be depleted. The demand and supply relation of rare earths is not like in a normal market where the supply could be increased depending on the demand. This is because the time required for discovering and producing rare earths and supplying them to the market is long. Hence, the consequence will especially be in reference to vulnerability of business models. What happens when parts of components cannot be available or cannot be produced? Or what will be the consequence if their price becomes many folds? These are strategic questions, with which the industry and the operator should deal with sooner rather than later.

A related example in the field of rail is a concept from different vehicle repair under the title "Obsolescence management". In this system, electric components of rail vehicle parts are collected and compared with producer's information on material availability. This serves on one hand to purchase with a reasonable price in time and on the other hand to observe the long-term availability of components. For railway vehicles (like installations of railway infrastructure), because of their extreme long lifecycles, developments related to this issues are of high importance. Like the question arise from the German rail company: "…where can I get a single component for construction groups with electric components after 30 years?" [20].

This research contributes a concept for a systematic information system to support solutions for common concerns of stakeholders in the sector of railway infrastructure. So far, there is no experience in the establishment of an information system in this sector; therefore, in this work, the first step was to minimize risks by conducting studies to clarify the extent of implementation of this system. Since the identification of the rare earths and assessment of their lifecycle paths in the railway infrastructure may involve different specializations, it is important first to assess these fields, in order to define the extent and application of the information system.

1.1. Contribution

This paper presents the results of a feasibility study conducted with the objectives to:

- study the fundamentals of the rare elements in rail infrastructure and to analyze their relevance in the sector of railway infrastructure,
- clarify the bias, if the focus should in principle be placed on the rare earths or to investigate and incorporate general critical metals like in the field of energy technology,
- develop the concept for an information system for the proper lifecycle management, beginning from the time of mining up to the disposal (recycling) time,
- propose the basic design of an information system for the evaluation and analysis of these elements based on those information.

These objectives could be achieved by performing a contextual analysis where the stakeholders such as infrastructure operators, industry, public or other interested parties were identified. The needs of the stakeholders for such an information system was studied. With these inputs, the basic design and the architecture of the information system could be specified.

The information system can provide a tool for operators of rail infrastructures to get a systematic overview on the application of rare earths elements and to make strategic decisions, e.g. substitution by other elements, cooperation with suppliers for alternatives, start own development up to a systematic consideration of the Life Cycle Cost (LCC). The application of this tool can highly contribute to companies, to observe the technological and economic development and to take timely precautionary measures.

2. BACKGROUND AND RATIONALE

Estimations from the U.S geological survey assume the availability of 110.000.000 tons of reserved rare earth metallic oxides globally. Yearly mining of these elements in the year 2012 is estimated to be 110.000 tons [7]. The following Figs. 1 and 2 show the global distribution of reserves and the mining amount in the year 2013 respectively.

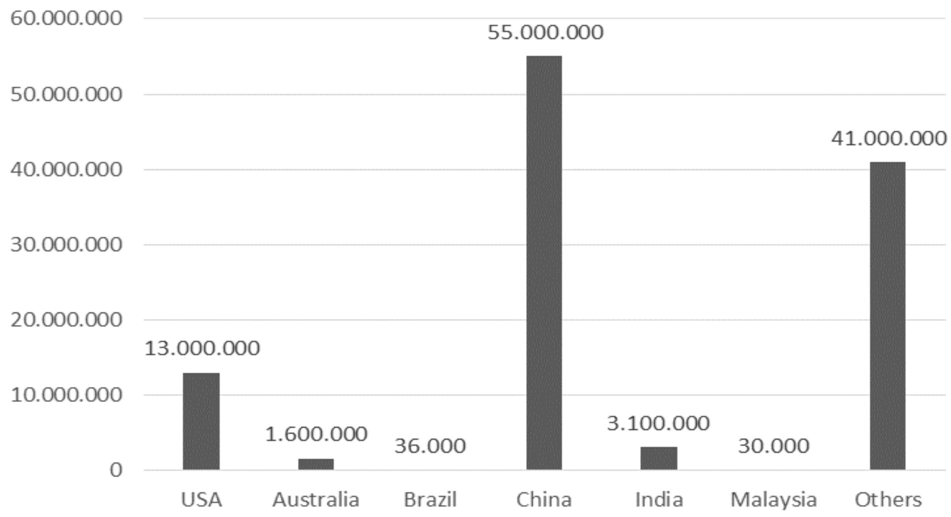


Fig. 1. Global rare earth reserves in tons. Source: [16]
Rys. 1. Globalne rezerwy pierwiastków rzadkich w tonach. Źródło: [16]

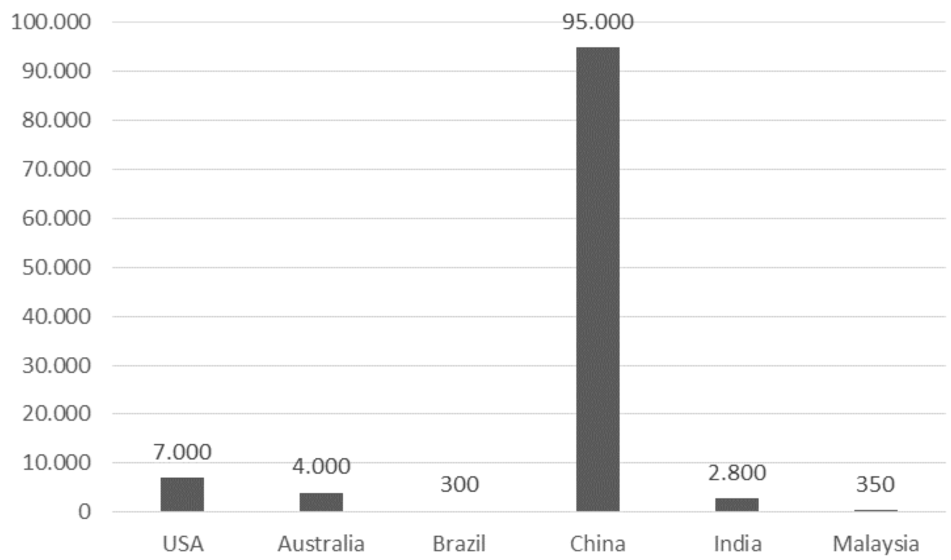


Fig. 2. Mining 2013, in tons. Source: [16]
Rys. 2. Górnictwo 2013 w tonach. Źródło: [16]

As it can be observed from the Figs. above, for example, china with the ownership of 48% all reserves, dominates the global mining by taking the lion's share of 86%. According to US department of energy [5], China announced that, the country may require imports by 2014 of certain rare earths, some that are deemed "critical" by the US Department of Energy. Moreover, main customers (importers) of these elements are Europe, Japan and the USA. Within EU, France take a big proportion of importing rare earths with 38%, followed by Austria with 24% [17]. Fig. 3 below shows the import share of rare earth elements in Europe. This increase in demand, as it is already being observed, leads to escalation of prices, for example in the year 2010, according to [6], so the prices for many rare earth oxides had risen over 500% in just few years. As a result countries began to re-evaluate old rare earth prospects and explore for new ones. This in the long run will advance to natural resource conflicts, where the shortage doesn't only imply a reduction in resources but is also a very political issue. Beside the economic and political aspects, there come environmental and social concerns related especially to the mining and processing of these elements.

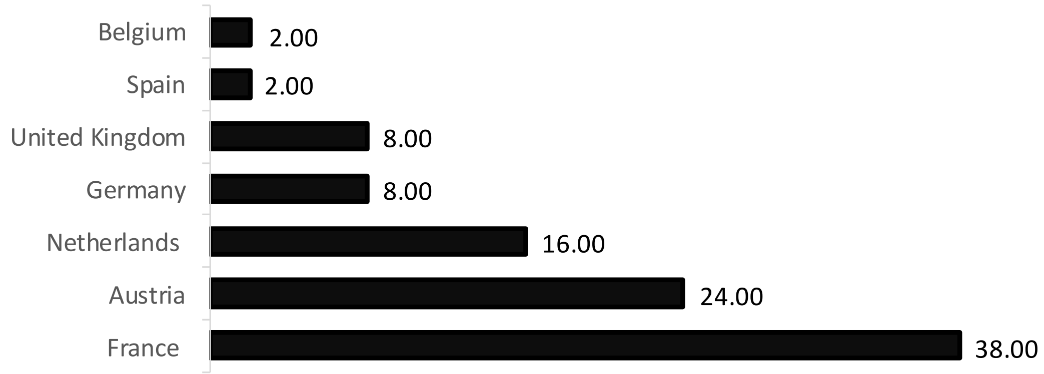


Fig. 3. Share of import of rare earths compositions in selected EU countries in the year 2010. Source: [21]
Rys. 3. Udział importu pierwiastków rzadkich w wybranych krajach UE w roku 2010. Źródło: [21]

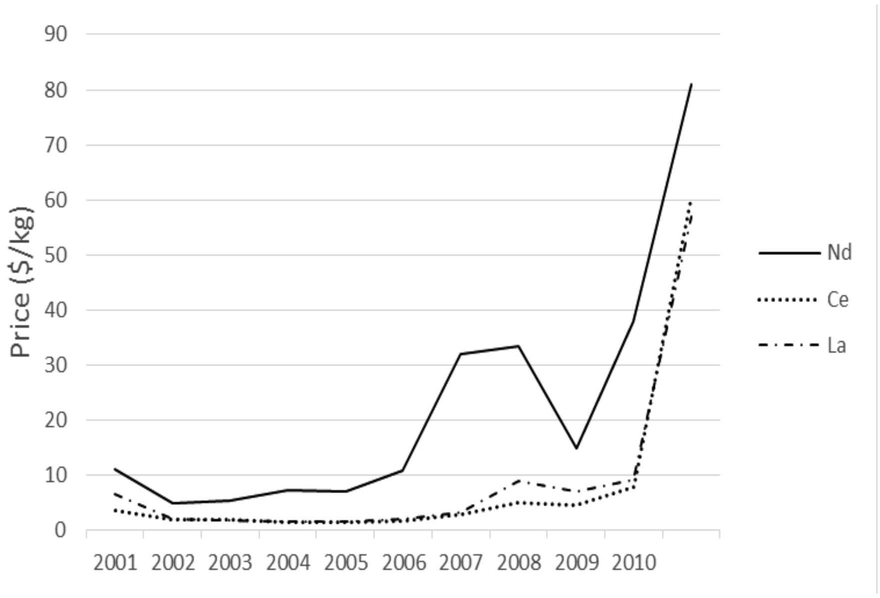
The following Figs. 4a and b illustrate the development of the price in relation to the shortage in supply of few cheap and expensive rare earth elements respectively.

Due to escalating increase in prices, manufacturers are obligated to take measures: (i) by seeking ways to reduce the amount of rare earth elements in production, (ii) seek alternative materials to replace them, (iii) to develop alternative products which do not require earth elements [6].

A comprehensive assessment on the use of critical metals in a given technological field is performed in 2011 with the work "Critical Metals in Strategic Energy Technologies. Assessing Rare Metals as Supply- Chain Bottlenecks in Low carbon Energy Technologies" [8]. With this work, performed by the team of experts, 14 metals were identified and classified as critical (Dysprosium, Neodymium, Tellurium, Gallium, Indium, Niobium, Vanadium, Tin, Selenium, Silver, Molybdenum, Hafnium, Nickel, Cadmium).

Under European Union, some political strategies are developed to the issue of rare earths and/or critical metals. For example in 2008, the first step in "The raw material initiative – meeting our critical needs for growth and jobs in Europe" [4]. An extended work is "Critical raw materials for the EU" [3], and/or the related initiative of the DG Enterprise and Industry, express and point out explicitly the urgency actions in this field. The commission is nevertheless convinced that information can be a key for a solution. In the work on the application of a completed material flow analysis for raw materials, the authors conclude that the data accessibility and data quality should be improved at all levels.

(a)



(b)

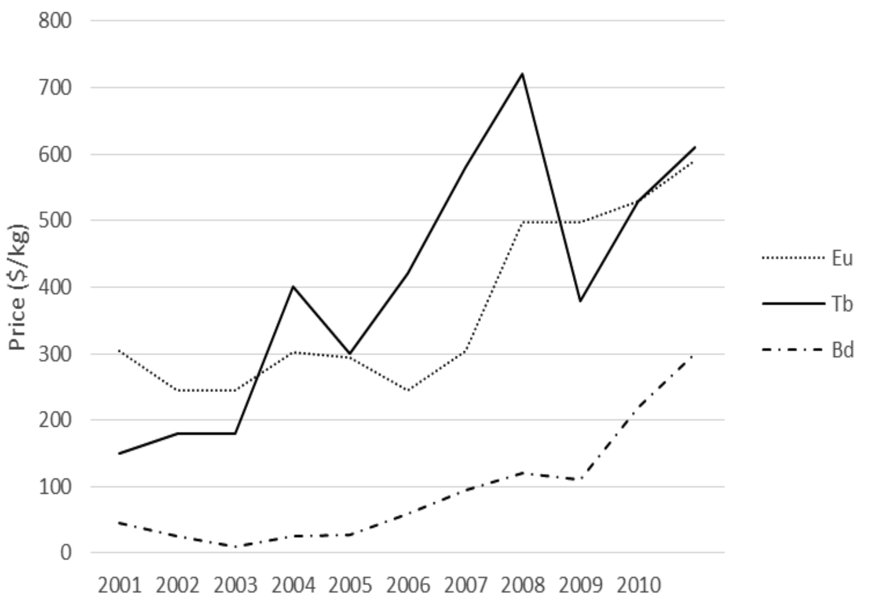


Fig. 4. Price development of rare earths, source: [17]
Rys. 4. Zmiany pierwiastków rzadkich, źródło: [17]

2.1. Data inquiry and analysis

The environmental database Ecoinvent is currently a globally leading Swiss Centre to capture, analyse, manage and provide lifecycle inventories. Ecoinvent is used in many lifecycle assessment tools to provide lifecycle data of products for analysis of their impacts on the environment. In the data record of Ecoinvent, provision of materials and processes are mapped. The data contains for example necessary materials and related processes in the production of one kg electronic component. Here, the occurrence of rare earths, which is important for this research, can be traced in three places.

Firstly, the rare earths can be part of the "Lifecycle Inventory Results", where proportions of emissions to the environment, as a result of energy, space and material transitions in the production of reference materials, can be listed. This includes, the applied energy sources and infrastructure, whose emission likewise be counted in.

Secondly, if someone needs to look whether rare earths are extracted from their natural resources, can refer to information gathered from material content of the products. Furthermore, rare earths can still be indicators of environmental impacts on the ecological scarcity, which facilitates the assessment of consumption of limited resources.

As a third possibility, rare earths can appear in material form directly under "Unit Process Exchanges", whereby a direct material flow and links which are referred to other data sets (in terms of material flow A + material flow B + X *production costs = 1 kg Reference material). If rare earths are found in a given material flow, its composition can be traced back until the roots of the chains are obtained and the pure raw materials are estimated.

Three different variants were reviewed: a) emission and resource consumption in a given data set of Ecoinvent, b) environmental indicators for ecological scarcity and c) material chain in EcoInvent.

As a conclusion, the way over an environmental data base is only possible in single cases, and for the information system, no usable solutions are presented. Although a data base can provide separate information about rare earths, however no usable information can be derived from them. As a second alternative, a research was performed on available studies in this field.

2.2. Research studies

Since the data analysis based on materials could not produce useful results, in order to get information, few available studies in the field of rare earths were assessed. This assessment helped to identify if a conclusion can be done on the contents of rare earths based on the knowledge of product components. There is a probability that this component-based approach instead of material-based approach is in chance of losing accuracy. However, the purchaser should only gain knowledge about the components contained in the product but no more the exact material mix of each part, which is essential to be user friendly and realistic in the application.

The data analysis has revealed the availability of numerous studies on rare earths (especially in scrap), to be able to construct an information system on the rare earths in railway infrastructure components. Especially studies on the electronic scraps showed critical components in terms of the contents of rare earths and their suitability in the disposal of mixed scraps. In the railway infrastructure, only few types of components contain rare earths whose concentration are sufficient enough for recycling. These structural components are for example, magnets, LEDs or printed circuit boards. In the searching processes components applied in space travel, medicine or the chemical industry could largely be excluded, which made the study easier.

In addition, there are studies which perform evaluation of rare earths like for example in "Critical raw materials for the EU" [3]. For different rare earths, there is obviously different supply criteria and (so far rather theoretical) recycling technologies. The information system should therefore also consider the level of criticality of the rare earths.

To be able to make statements on the contents of the rare earths in components, the information system should use data from the available studies. The use of environmental database is meaningful only occasionally. The information system should especially deal with those components and/or structural groups, which contain this. The derived procedures should not always be the same: for example it is simple to remove the circuit board of a given obsolete control computer and to feed it to the recycling, however, it will be hard to reach to silver containing connections in a closed power supply. Nevertheless, if both components should be documented in the information system, because of their contents of rare earths; efforts should be done to react on improvements in scrap sorting in the future. This supports to reveal the weak points in the applied products.

2.3. Example from railway infrastructure: Purchase of a switch motor

This components are needed to bring up the mechanical power for the switch process. Requirements are high mechanical and signalling reliability, even in extreme weather and temperature conditions. In these structural groups, there is an electric motor and possibly a small board that can contain rare earths. A new electric motor could be made of neodymium permanent magnet, which the purchaser should find out.

These motors have according to [2] a neodymium proportion of 5% and besides small proportions of dysprosium, to make the magnet heat resistance. The magnets by themselves have according to [5] a neodymium proportion of 31% and dysprosium proportion of 5.5%.

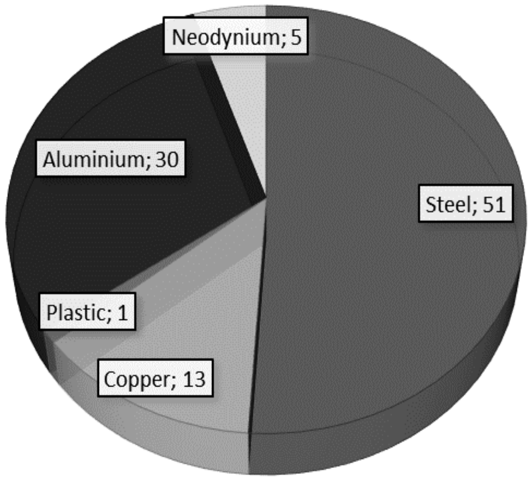


Fig. 5. Proportion of materials in an electric motor in %. Source: [2]
Rys. 5. Proporcja materiałów w silniku elektrycznym w %. Źródło: [2]

The circuit board can contain different rare earths. However, the type of rare earths always depend on each application of the circuit boards. Elements in the circuit board, which usually appear in high and recycling relevant concentration are the following:

In a circuit board appear mostly: gold (Au), cobalt (Co), palladium (Pd), Platin (Pt), Antimon (Sb), Zinn (Sn) and based on the application also: germanium (Ge), lanthanum (La), Tantalum (Ta) and Wolfram (W).

3. TARGET GROUPS AND REQUIREMENTS

Target groups of this information system are departments accountable for purchasing, for maintenance and disposal as well as responsible technicians of small and big industries. In small industries, fields of purchase, maintenance and disposal can be defined as target groups. In big industries, the purchasing department represents the strategic management level and competent bodies for product politics. The requirements of these groups in terms of the integration of the system in different work processes and display of information are different.

By the application of this information system technicians or purchasers will get a tool to examine the components related to rare earths. With the inputs of qualitative data, like for example big/small power supply, number of LED luminaires and so on one can refer to rare earths without including the exact material or extents. This tool can be embedded in strategic purchasing process or by technicians in the production process.

In the formulation of criteria to bid, a provision of an interface for a database, which contains information about materials (e.g rare earths) should be demanded from supplying companies. For the supplying company the application of this tool means finding the bottlenecks through the analysis of components produced or bought by them.

By the use of this application, a positive contribution should be achieved for environmental protection and against exploitation of the earth. In the future, by the innovation of alternative products without rare earths, bottlenecks can be avoided.

From an online interview with 27 participants as well as telephone interviews with selected experts from the field of railway infrastructure, the demand for this information system and the topic of the rare earths is confirmed. Here a general lack of knowledge, in reference to rare earths could be identified. Only limited participants indicated that they discuss about rare earths in the working environment.

By integration of the tool, an important contribution can be achieved in raising awareness for rare earths within railway sectors as well as suppliers.

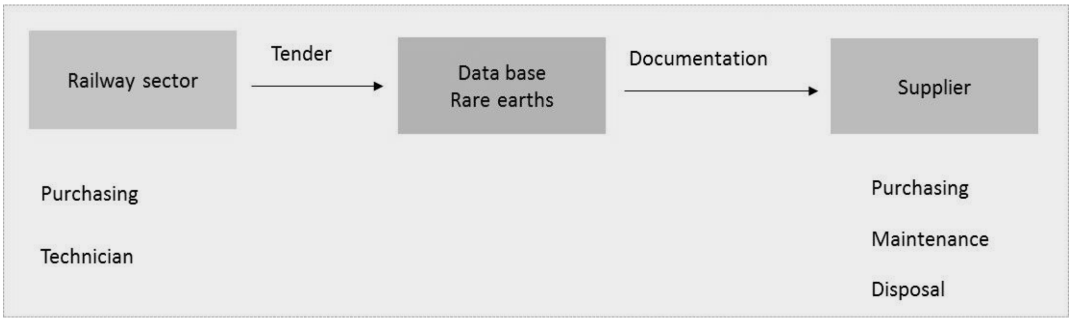


Fig. 6. Application areas
Rys. 6. Obszary zastosowań

4. CONCEPT OF THE INFORMATION SYSTEM

4.1. Integration of the information system in to existing systems or application as a stand-alone application

Existing systems e.g. connects different relevant business divisions in a one evaluation tool. Users have access to collect data in areas like inventory management, geographic data, road atlas, repair, diagnosis, documents, and costs of in maintenance, and develop corresponding results. The quality and security management tool developed for European infrastructure and traffic companies could be integrated for rare earths as a module. Several interfaces to management systems documents and ERP-Systems are supposed to be included. Hence, by embedding this in the field of environmental protection, further aspect can be incorporated within the strategic decisions.

Beside the possibility of integration, the tool for rare earth elements can also be seen as a stand-alone version. Here several representations of rare earths could be realized and be used as application tool for environmental issues. Possible visualizations might be:

- overview about important rare earth elements
- illustration of materials with occurrence of rare earths at the component level, linked to the time of action with expected exchange of components.

4.2. Ecodesign plus – Ecodesign

ECODESIGN+ is a software to compute environmental effects at the stage of product development. Designers obtain with ECODESIGN+ a tool that extracts data (material, measures…) from CAD – software of the production designer process and utilize it for ecobalance [18]. As a result, cumbersome, complex and expensive work processes can be eliminated. Designers can concentrate on the product; during ECODESIGN+ make a visual feedback on the environmental effects of the design of products available.

The tool developed by Ecodesign can be used as a reference to develop the information system. Here it is not only the environmental effects during product development to be evaluated and analyzed, but components with rare earths are recorded and this can be observed in the areas of purchasing, maintenance and disposal.

The current database status does not allow assessment at material level. Information are found namely on rare earths which are connected to material inputs of steel/aluminium/PET. These are neither completed nor can inform the exclusive existence the rare earths in the corresponding product. There is lack of information on the indirect existence of the rare earths in various aspects of material production.

The amount of rare earths in a given material cannot be determined, but the assessment can be performed at component level. It can be ascertained in which structural groups rare earths are found. In the purchasing data, it is possible for example to read out if there exist a big or small network part or if a certain process unit is installed in the structural part. Since these parts are critical and contain rare earths relevant for recycling, these data are appropriate to develop this information system and apply it reasonably. The users can here use the weight of the component as an input. As another alternative to simplify the process, they demand qualitative information, like the amount and forms of components in the system. In the background, types will then be replaced by assumptions.

4.3. Information system data input and evaluation process

Small companies:

The input and the modelling of the structural components is acquired through the input mask within the information system. At the supply level, a data set will be created for information to the corresponding order like name of the company, order number, service time, maintenance and disposal contracts and so on. After the creation of this basic information, the structural components that are necessary for the order will be modelled. Here information for the type of the structural component, appearance, number, application area and useful life within the company will be defined. The choice of the corresponding parameter is performed through the choice of the predefined entries. These inputs to the structural component will in the background be compared to the database to identify the rare earths and their amount (fig. 7).

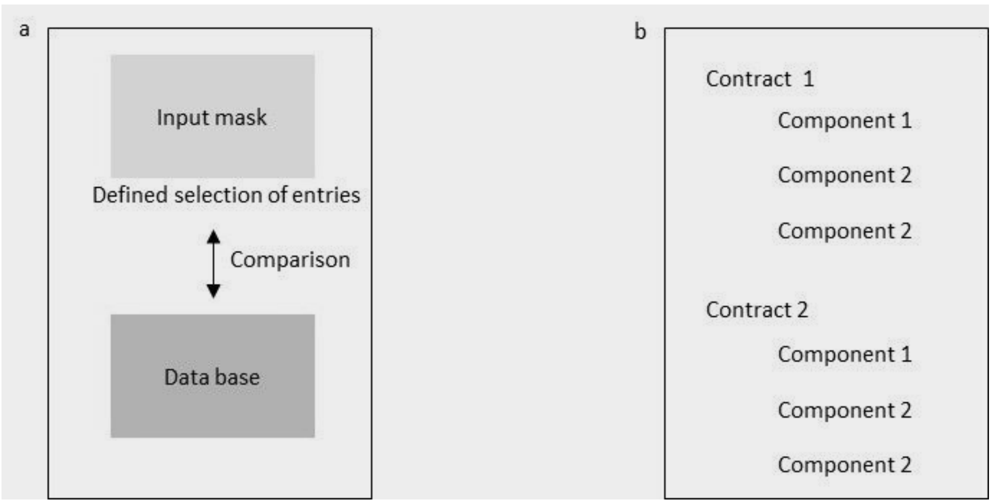


Fig. 7. Input and modelling of offers: (a) information hierarchy, (b) input mask
Rys. 7. Wejście i modelowanie ofert: (a) hierarchia informacji, (b) maska wprowadzania

After the input of the structural component at the level of contract (Fig. 7(b)), the user receive different views and diagrams ready for analysis.

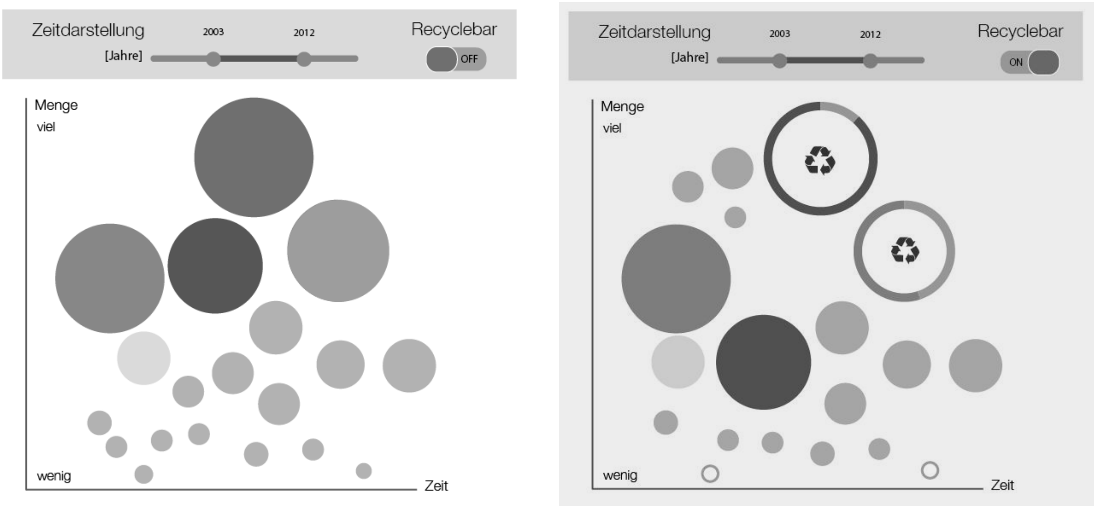


Fig. 8. Overview of all contracts and occurrence of rare earths
Rys. 8. Przegląd wszystkich umów i występowania pierwiastków rzadkich

A scatter plot will be used as a visualization type to illustrate an overview of the amount of rare earths as shown in Fig. 8. The size of the circles and their position in the y- axis show the amount of the structural components contained in the order of the customers. On the x-axis the chronology of the orders are illustrated and can be restricted by a slider. The smaller the circle on the scatter plot and the far down it is positioned, the smaller rare earths are contained in the whole structural component within the corresponding order. This view can be switched to recyclable elements within the order of the customer by the toggle element.

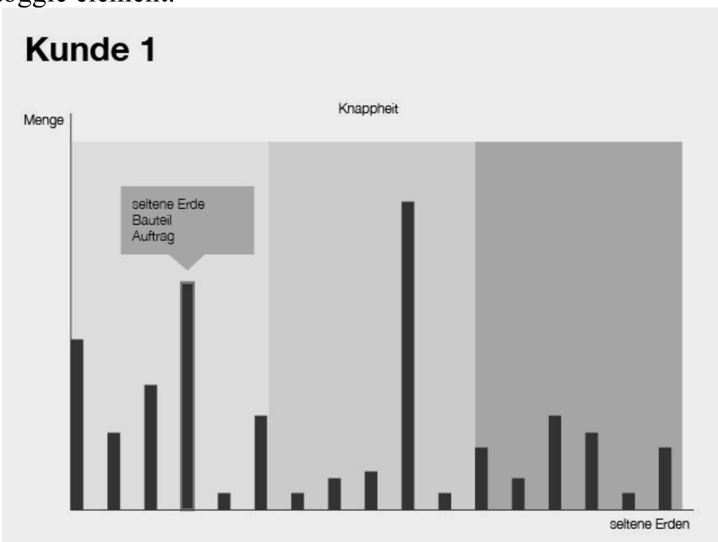


Fig. 9. Overview of rare earths and their scarcity
Rys. 9. Przegląd pierwiastków rzadkich i ich niedostatek

The exact information on the individual components, which can contain rare earths at the contract level, can be called by clicking on the corresponding circle. The 17 elements of the rare earths are conFig.d in categories based on the scarcity and visualized by a bar diagram (Fig. 10). Here the users get an overview about the rare earths that are contained in the structural component within the corresponding order, additionally get information on the scarcity of the rare earths.

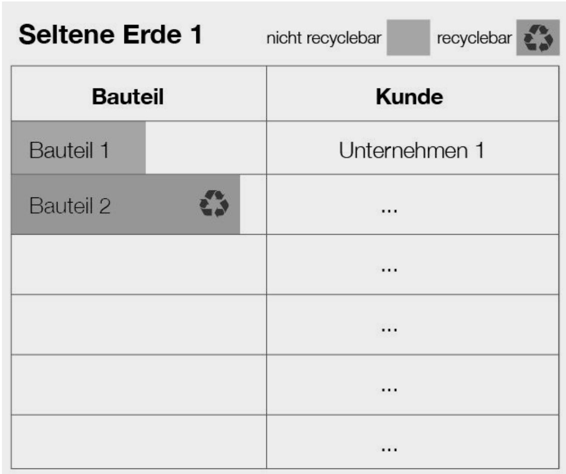


Fig. 10. Table - all components with share of rare earths
Rys. 10. Tabela - wszystkie komponenty z udziałem pierwiastków rzadkich

Subsequently, the corresponding rare earth can be navigated in order to identify the components, which contain them. A table, which lists all components in connection with occurrence of rare earths, will be integrated as a further illustration form (Fig. 10). In this view, an analysis tool for strategic decision can be created by: (i) the link of information of the rare earths with information, (ii) the possibility of the recycling through the illustration, (iii) the amount of rare earths as bar and a coloured coding. The inputs within the tables will be sorted according to the amount of the rare earths.

Fig. 11. Details on demand offerings
Rys. 11. Szczegółowe informacje na temat oferty na żądanie

There will also be a list of all supplies (fig. 11) which can be displayed on the interface of the information system. Here all supplies of the small company will be listed. Additionally, the information of the recycling of the individual components will be presented in detail.

The table shown in Fig. 10 can also be provided as documentation for big companies, which appear as clients. Invitations of tenders contain mostly criteria, which a delivering company should consider. Therefore, this can be sent to the company during the application, in order to present the current status on the rare earths within the company and the corresponding component.

For technicians using this information system as analysis tool, the views mentioned above will likewise be integrated in the system. Additionally, the following illustrations may be interesting for the target groups.

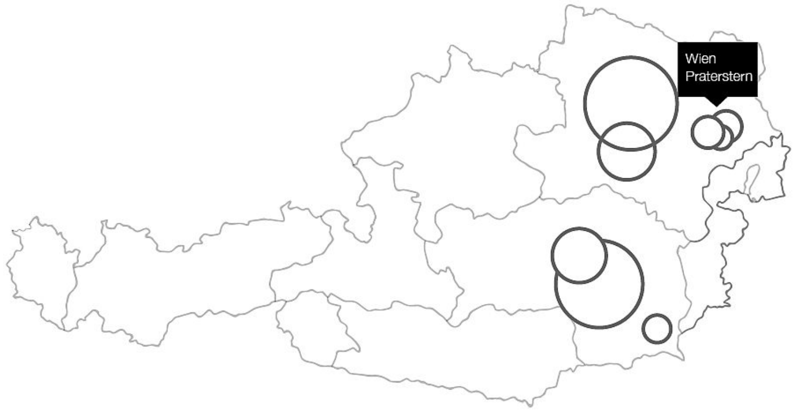


Fig. 12. View map with amount of rare earths
Rys. 12. Widok mapy z ilością pierwiastków rzadkich

A general view for the whole Austria can be detailed by zooming of the corresponding state or location such as organizational unit. The circles illustrate the amount of the rare earths and their location of occurrence.

5. CONCLUSION

The work carried out shows, that there are still large gaps in the knowledge about rare earths in the field of railway infrastructure. Interestingly, for the individuals, the subject and the resulting problems are known, but for the companies, the subject is not yet on the agenda. Above all, the individual interviews have shown that the experts believe that the topic ‘rare earths’ will have a very great importance in the near future. The use of a tool that provides an overview of rare earths, or on the components containing rare earth, was deemed as necessary in the future. Whether this tool is stand-alone, or integrated into existing systems this plays a minor role. The proposal developed here serves basically as a first attempt for approach for an information system which can be continued with further developments.

Acknowledgements

The authors would like to acknowledge the financial support from the Federal Ministry for Transport, Innovation and Technology in Austria (bmvit) within the program “Mobilität der Zukunft”.

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Received 19.11.2014; accepted in revised form 26.11.2015