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CSH Study

Transformation opportunities for Austria in the "Tech for Green" sector

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About the Complexity Science Hub Vienna

The Complexity Science Hub Vienna was founded with the vision to become the focal point of complexity science in Europe. The aim is to provide an exciting, creative environment free of bureaucratic constraints for open-minded visionaries who are brave enough to step out of mainstream science. The Hub will be an incubator and playground for radically new ideas. It is a node in a network of international partner institutions, including the Santa Fe Institute, the Complexity Institute at Nanyang Technological University Singapore, Arizona State University, and the Institute for Advanced Study Amsterdam. Through this network a lively exchange of scientists, question posers, students, and postdocs is envisioned, enabling the most important exchange – that of ideas.

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Executive summary

Austria is committed to the Sustainable Development Goals and to become climate neutral until the year 2040. The transition to a greener economy will lead to a change of the goods and services Austria produces. In the theory of Economic Complexity, each country has capabilities that enable it to produce different products [1]. The set of capabilities is determined by the geographical conditions of a country, its workforce, available technology and infrastructure. A country with a diverse set of capabilities can, in general, produce more complex products which correlates with higher income. Countries differ in their capabilities and therefore also in the goods they are producing. This translates to their specific location in the so-called Product Space [2]. In the Product Space, the distance between two products depends on the similarity of their required capabilities. For example, trousers and shirts are located close to each other, but far away from computer chips. It has been empirically shown that countries move through the Product Space by developing goods close to those they currently produce [2].

In this exploratory study, we identify green products for which Austria already has most of the required capabilities and which therefore offer opportunities for Austria's green economic development. We discuss the global market size and analyze the identified products for their dependence on critical materials. We further determine the regions of Austria which are well suited to produce these products and compare the results for Austria with the green development opportunities for Germany and Switzerland.

What are "Green" products?

We define green products by following the Organisation for Economic Co-operation and Development (OECD)'s 1999 working definition, according to which environmental goods are those that *"[...] measure, prevent, limit, minimize, or correct environmental damage to water, air, and soil, as well as problems related to waste, noise and ecosystems. This includes cleaner technologies, products, and services that reduce environmental risk and minimize pollution and resource use."* [3] This definition is used by the international trade organizations OECD, World Trade Organization (WTO) and the Asia-Pacific Economic Cooperation (APEC) to compile lists of green products for which tariff exemptions are granted. Following the work on Green Economic Complexity by Mealy & Teytelblom [4], we use these lists to identify green products in Austria's product portfolio. We find that Austria's green products tend to be complex products and mostly belong to the Machinery/Electrical equipment (52%) section of the Harmonized System (HS) product classification [5]. We find that Austria already produces 41 of 75 green products competitively.

The Green Adjacent Possible (GAP)

We identify the green products that are closest to Austria's current position in the Product Space, but not produced yet. This set of "adjacent" green products is called the "Green Adjacent Possible" (GAP) [4]. More than half (57%) of the products in Austria's GAP are classified as "Machinery". The three products closest to Austria's current export basket have environmental benefits relating to wastewater treatment or reduction. Other products in the GAP relate to green energy production or the reduction of energy consumption.

We further identify a subset of five products that are characterized by a high product complexity [1] and a large global export volume and therefore represent Austria's most attractive green diversification opportunities:

- Automatic regulating instruments (HS2012: 9032)
- Pumps for liquids (HS2012: 8413)
- Pumps, compressors, fans, etc. (HS2012: 8414)
- Appliances for thermostatically controlled valves (HS2012: 8481)
- Instruments for measuring properties of liquids (HS2012: 9031)

Critical materials

We analyze these products for their dependence on critical materials and find that "Automatic regulating instruments", "Pumps, compressors, fans, etc." and "Instruments for measuring properties of liquids" might contain some critical minerals like Indium, Chromium or Cobalt whose supply is largely controlled by single countries. In order to be resilient towards possible supply shocks, future manufacturers of these GAP products should carefully observe the world market situation of these critical materials and explore recycling opportunities. The manufacturing of non-digital variants of these products should also be considered, as those tend to contain less critical materials.

Regional and international comparison of green development opportunities

The capabilities for producing the identified green products are distributed unevenly across Austria. We pinpoint the federal states of Austria that are best suited for the production of these products. States such as Tyrol, Vorarlberg and Styria are expected to have a competitive advantage to produce the identified green products, whilst Burgenland and Carinthya are relatively disadvantaged. Furthermore, we determine the GAP for every Austrian federal state to highlight regional green development opportunities. Despite the similar economic structure of Germany and Switzerland, we find differing green development opportunities. This highlights the method's ability to capture fine-grained differences in product portfolios and to identify specific green development opportunities.

Dashboard

We create visualizations of our results and publish them in an interactive dashboard. This enables policy makers and the general public to explore Austria's Economic Complexity and Green Transformation Opportunities (ECTO) to make informed decisions about Austria's green economic development. The ECTO-dashboard is published under: https://ecto.rfte.at/

Introduction

Austria and most other countries have reached a social consensus that decarbonizing the economy is inevitable in the face of the global climate crisis. Austria's goal of climate neutrality by 2040 needs ambitious decarbonization of current production methods in established industries on the one hand, but on the other hand also requires promoting new, green technologies and products. Ambitious roadmaps and a faster transition to a climate-neutral economy are key to establishing market leadership in green technologies [4]. In this study, we identify green products that are currently not significantly produced and represent a special opportunity for Austria to establish itself as a frontrunner in the market for green products in the future. Here, we define “green” not only as carbon-emission free but take a broader approach that includes all kinds of environmental benefits.

In the theory of Economic Complexity [1], [2], each country has capabilities that allow it to produce different products. The set of capabilities is determined by the geographical conditions of a country, its workforce, available technology and infrastructure, as well as other, often intangible factors. A country with a diverse set of capabilities can, in general, produce more complex products which correlates with higher income. Countries differ in their capabilities and therefore also in the goods they are producing. Because these capabilities are often not directly observable and quantifiable, the theory of Economic Complexity determines them indirectly based on import/export data. Based on the insight that some products require similar and some require completely different technological and societal conditions, the so-called Product Space can be constructed [2]. The nodes in the Product Space are goods, and the distances between the goods in the Product Space represent the similarity of the underlying technologies or their prerequisites. For example, trousers and shirts are located close to each other in the Product Space, but far away from computer chips.

It has been empirically shown that the Product Space can predict the future development of a country's product portfolio, for example market entry or growth in certain goods [4]. Based on prior work [4], we know that Austria has a favorable position in the Product Space regarding the further diversification in green products. We extend the work by Mealy & Teytelboym (2020) [4] by identifying (groups of) green products for whose production Austria has favorable conditions. We analyze the identified products for their dependence on critical materials and determine the regions of Austria which are well suited to produce these products. Finally, we compare the results for Austria with the green development opportunities for Germany and Switzerland.

Key points of the study:

1. Identify technologies and products relevant for the green transition.
2. Determination of the development potential of the identified products for Austria.
3. Evaluation of products and development potential according to demand for and origin of critical materials.
4. Regional analysis of the results in Austria.
5. International comparison of the dimensions listed above.

Data & Methods

We base our analysis on international trade data. Focusing on exports allows us to identify products that a country can produce internationally competitively. Trade data is collected in the United Nations COMTRADE database and can be accessed and bulk-downloaded in a cleaned version through the Harvard Dataverse [6]. Here, we are using product data classified using the Harmonized System (HS) in its 1992 revision on the 4-digit level. HS codes are structured hierarchically, an example is provided in Tab. 1.

Code	Description
Section VI	Plastics / Rubbers
40	Rubber and articles thereof
4011	New pneumatic tyres, of rubber.
401110	New pneumatic tyres, of rubber; of a kind used on motor cars (including station wagons and racing cars)

Tab. 1. *Example for different levels of granularity of HS1992 codes. Longer digits specify products more accurately.*

How are capabilities measured in the Economic Complexity framework?

Before we construct the Product Space, we identify which products are exported competitively by each country. For this we use the Revealed Comparative Advantage (RCA)[7],

$$RCA_{c,i} = \frac{x(c,i)}{\sum_i x(c,i)} / \frac{\sum_c x(c,i)}{\sum_{c,i} x(c,i)}, \quad (1)$$

where $x(c, i)$ denotes the export volume of country *c* in good *i*. The RCA compares the share of good *i* in country *c*'s export basket to the product's share in the "average" export basket.

We construct the Product Space by defining a proximity that relates two products in terms of the similarity of the underlying capabilities. We use Hidalgo et al.'s definition of 'product proximity' Φ_{ij} [3],

$$\Phi_{ij} = \left(P(RCA_i > 1 \mid RCA_j > 1\right), P(RCA_j > 1 \mid RCA_i > 1)). \quad (2)$$

Here, $P(RCA_i > 1 | RCA_j > 1)$ is the conditional probability that a country is competitive in good i if it is competitive in good j. The minimum ensures that the proximity measure is symmetric $\Phi_{ij} = \Phi_{ji}$.

Proximity in the Product Space is predictive of whether a country will start to export a certain product in the future [2]. Products close to existing products are more likely to be exported competitively in the future. To quantify how related a product *i* is to the current export basket of a country *c*, we use a quantity called *density*, or, equivalently, *Product Space density* [2],

$$\omega_{c,i} = \frac{\sum_j M_{c,j}\Phi_{ij}}{\sum_j \Phi_{ij}}. \quad (3)$$

Where M denotes a binary product-country matrix that denotes whether a product is exported competitively, $M_{c,i}$, if $RCA_{c,i} > 1$ and 0 otherwise.

Using $M_{c,i}$, we can calculate the diversification of a country, as the number of products it exports competitively, and the ubiquity of a product, defined as the number of countries in which a product is produced competitively. We find that countries that produce many different products (high diversity) are able to produce relatively rare procuts (low ubiquity), and countries that export only few products (low diversity) produce only goods that are produced in many countries (high ubiquity). The intuition is that countries with many capabilities can produce a diverse set of products, including products that are very complex, and countries with few capabilities can only produce simple products. Generalizing on the concepts of diversity and ubiquity, the Economic Complexity Index (ECI) quantifies the diversity and complexity of a country's export basket. It is higher when a country produces many different and more complex products. The Product Complexity Index (PCI) measures the complexity of a specific product. When a product is produced only by a small number of complex countries, we infer that the product requires a high level of know-how and sophistication of production capability, which infers a high product complexity. Categories such as machinery, electronics or chemicals tend to have a higher PCI than raw materials such as ores, oil or agricultural products. A longer and more formal definition of the ECI and PCI can be found in [8].

The Product Space

Computing the proximities Φ_{ij} for every product pair *i* and *j* results in the matrix Φ that can be interpreted as an adjacency matrix defining a network. In the following we will refer to this network as the "Product Space" that shows how related products are. Products are closely related if they depend on similar capabilities and are dissimilar if they require very distinct sets of capabilities. In Fig. 1 we show a rendering of the Product Space. To make the figure less cluttered, we reduce the number of shown links by only showing the union of the maximum spanning tree and all links satisfying $\Phi_{ij} > 0.5$. The network shows a core-periphery structure. The core of the network is composed mostly of complex products that require many and diverse capabilities, such as machinery or chemical products. The periphery contains products that are comparably simple and require fewer capabilities that are not shared with many other products, such as agricultural or mining products. The nodes in Fig. 1 are colored by broad product categories. Products of one group are clustered together, for example in the right part of Fig. 1 a group of red nodes marks a cluster of textile products.

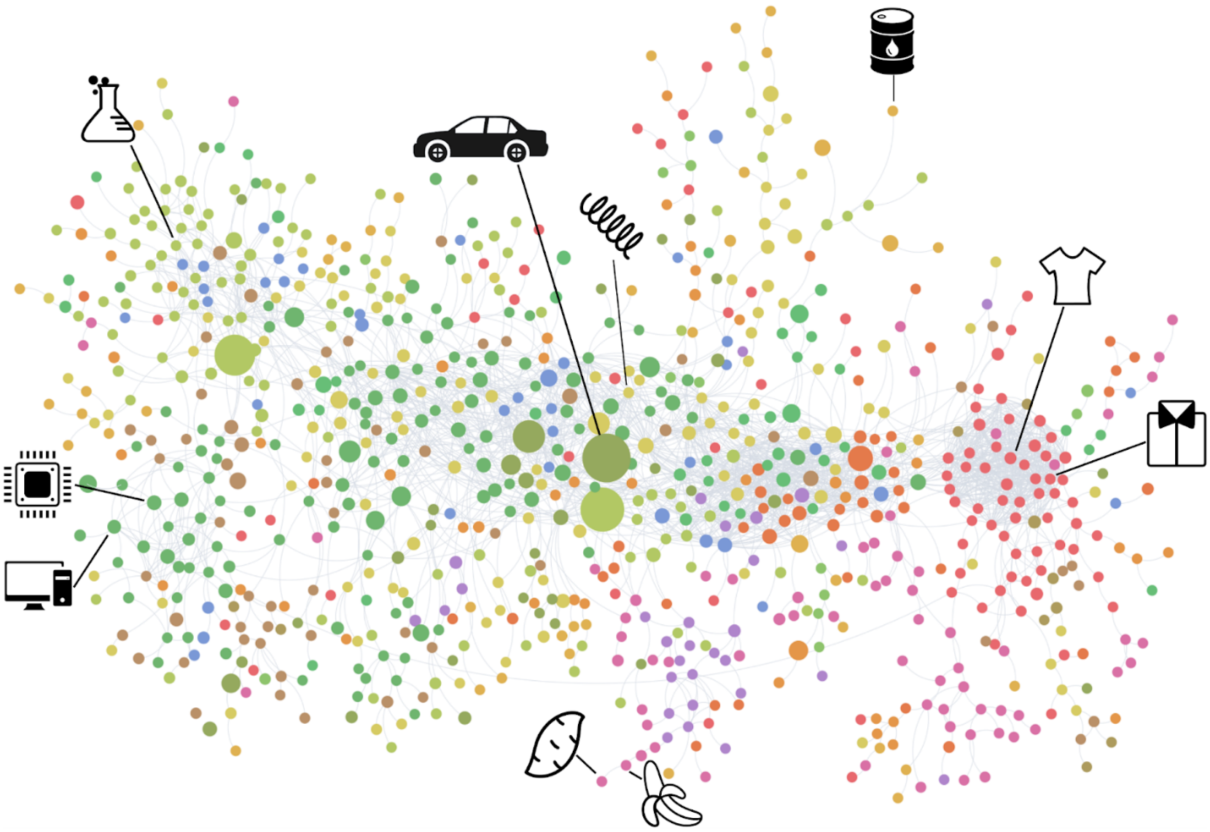

Fig. 1. *The Product Space. Each node represents a product, edges mark the similarity of two products. The more often two products are produced together in a country, the closer they are to each other in the Product Space. The nodes are colored according to product groups. Complex products (chemical products, machinery) are located in the center, simpler ones (agriculture, raw materials) in the periphery of the Product Space.*

The Product Space is predictive for product entry [4], [9]. Already in the original research work introducing the Product Space the authors show that if a closely related product is already produced, this increases the probability that a given product will be produced in the future [2]. This insight allows to model the long-term evolution of a country's export basket as a diffusion on the Product Space. The predictive power increases over longer time horizons [10].

Austria in the Product Space

Fig. 2 shows a tree map of Austrian exports in 2020. Apart from services, which are not considered in this analysis, Austria mostly exports machinery, chemicals and car parts. As most products of these categories are located in the core of the Product Space, they tend to have a higher PCI. This is also reflected by the location of Austria in the Product Space. Fig. 3 shows the products Austria exports competitively, marked as full circles in the Product Space. Austria primarily exports products that tend to be more complex and in the center of the Product Space. This results in Austria's economy being capable of exporting many goods which translates into a high ECI value. Austria's ECI ranks 7th of 133 countries [8], [11]. It has a higher ECI than would be expected for its GDP per capita, meaning it outperforms its expected Economic Complexity.

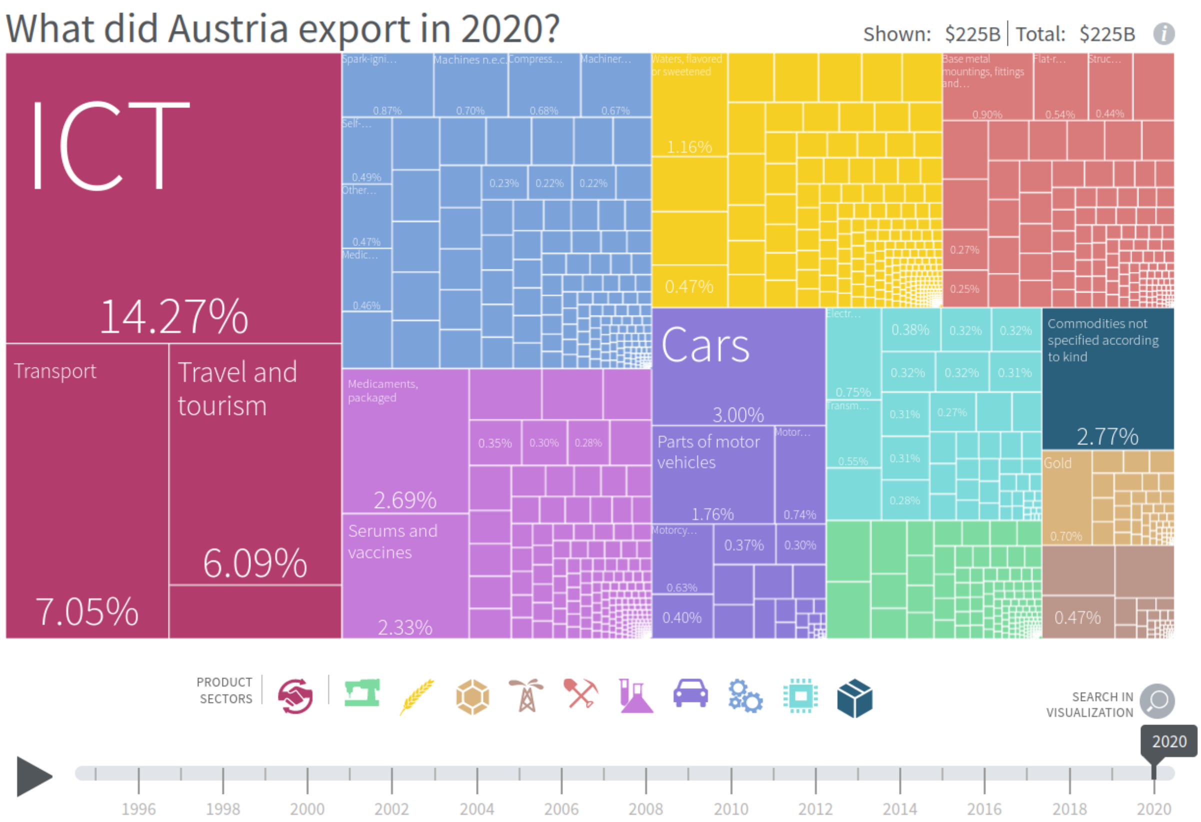

Fig. 2. *Austria's exports of the year 2020 visualized as a tree map. Apart from services (dark red), Austria mostly exports machinery (light blue), chemicals (violet) and car parts (purple). These categories also tend to have a higher product complexity. Source: https://atlas.cid.harvard.edu/ [8]*

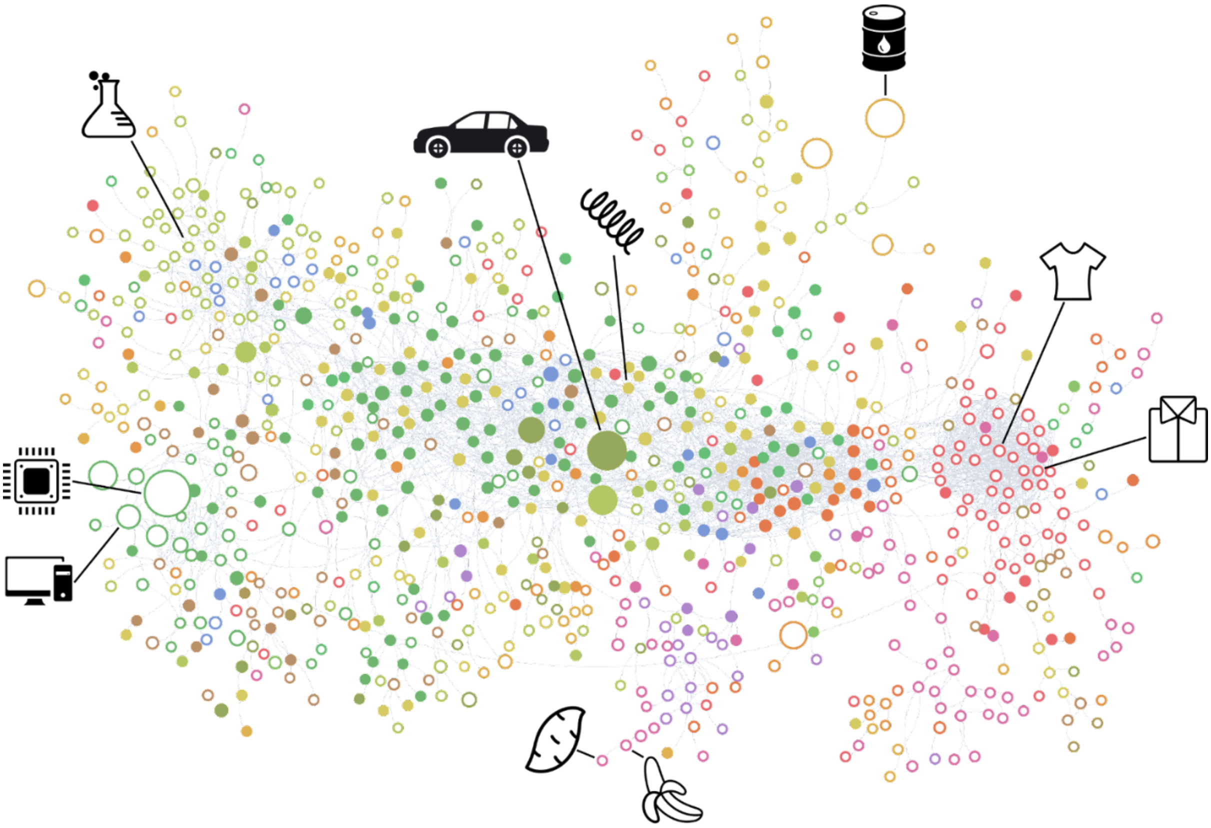

Fig. 3. *Plot of the Product Space. Filled nodes are products which are already competitively produced in Austria. These products tend to be located in the center of the Product Space, indicating high product complexity.*

Austria's opportunities for new green products

In the first work package we identify products that are central to the green transition and that have a particularly high growth potential in Austria. In a literature review the necessary data sources are identified. Subsequently, based on international trade data, growth potentials and market entry opportunities for product groups are identified.

Results of this work package:

- List of green products, compiled based on existing literature.
- Growth potentials for goods based on the theory of "Economic Complexity".
- Identification of green goods with high growth opportunities.

Green products

Multiple definitions coexist as to what constitutes an environmental good. One such example corresponds to the OECD's 1999 working definition, according to which environmental goods are those that "*measure, prevent, limit, minimize, or correct environmental damage to water, air, and soil, as well as problems related to waste, noise and ecosystems. This includes cleaner technologies, products, and services that reduce environmental risk and minimize pollution and resource use*." [3]

In a recent publication, Mealy & Teytelblom (2020) identify three institutional sources of lists of goods beneficial to the environment [1]. The OECD, the WTO, and the APEC, respectively, have published such lists with the purpose of implementing tariff-breaks for green products. While the WTO's Environmental Goods Agreement [12] is still being debated and no consensus has been reached around one specific list of products, the APEC list published in 2012 [13] includes 54 specific HS codes, and will likely be updated soon. The OECD's list [14] is a combination of three different sources (the Friends' list [9], the APEC list [13], and a modified version of the PEGS list) and comprises 248 codes [14].

Four observations are noteworthy. First, the lists focus on components, rather than end products. For instance, windmills for renewable energy are not included, whereas several of its components, such as wind turbines, are. Second, the lists qualify products in terms of their potential environmental benefit. In other words, goods like (wind) turbines are dual use and may have environmental and non-environmental purposes. When this happens, further descriptions called "ex-outs" are provided such that the environmental application is made explicit. Third, no information is available concerning the production process: the focus is entirely on use-oriented benefits. Therefore, no examination can be done concerning the lifecycle of the green products. Fourth, environmental services are not included yet. Since services and goods may sometimes be strictly intertwined, such as the knowledge of fixing an electric vehicle, a renegotiation of the Environmental Goods Agreement will likely lead to an expansion of the current list.

Fig. 4 shows the location of the green goods in the Product Space. They tend to be more central in the Product Space and have higher than average PCIs [4]. Most green products belong to the Machinery/Electrical equipment (52%) and Metal (15%) chapters of the HS classification.

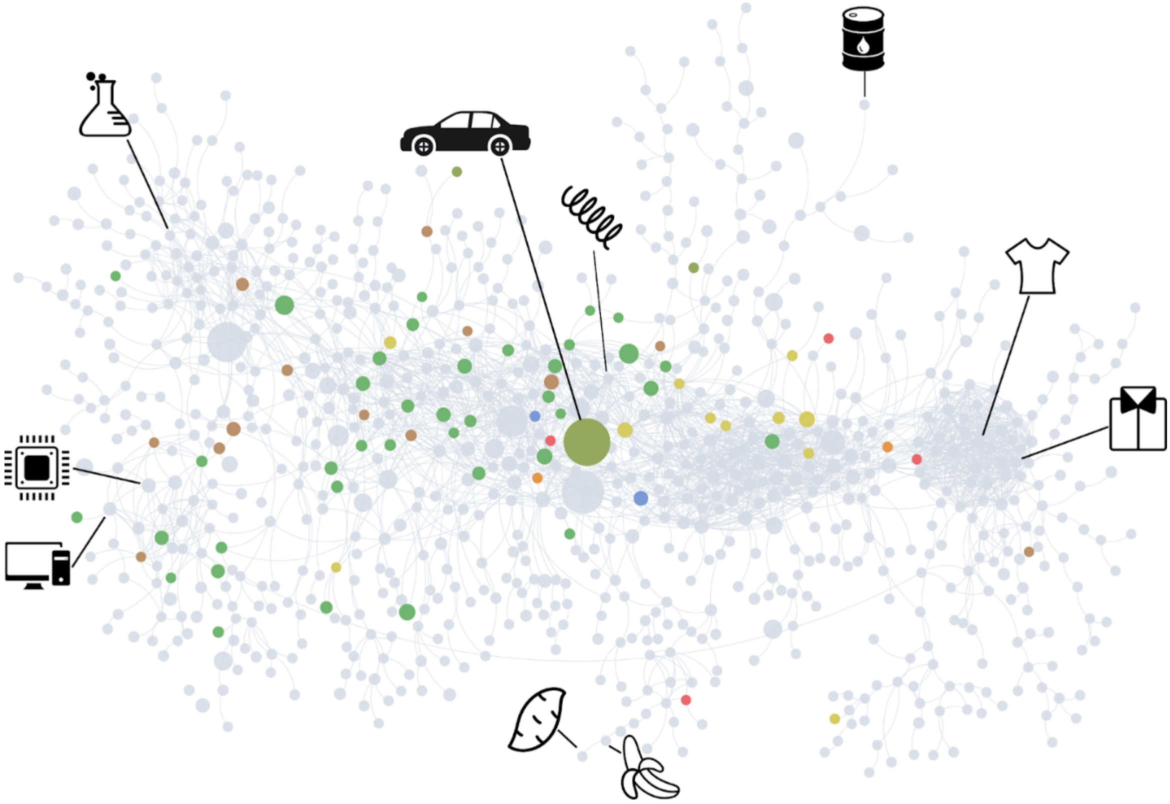

Fig. 4. *Position of WTO green goods in the Product Space. They tend to be more central, and more complex Mealy & Teytelblom (2020) [1].*

Austria, green products, and the Product Space

We compare Austria's export basket and the set of green products identified above by showing them both simultaneously in the Product Space, see Fig. 5. Austria already produces 56% of the identified green products (filled nodes with black outline). Many of the currently not produced green products (empty nodes with black outline) are in the vicinity of the currently manufactured goods and, hence, good candidates for green diversification opportunities. We will elaborate on this in the next section. The fact that Austria already produces many green products and that the other green products are closely related to its current product portfolio suggest that Austria's set of capabilities is well suited to produce green products. In fact, Mealy & Teytelblom [4] define the "Green Complexity Index" (GCI) to quantify "the extent to which countries can competitively export a diverse range of technologically sophisticated green products". Austria ranks fourth in GCI, after Germany, Italy and the United States.

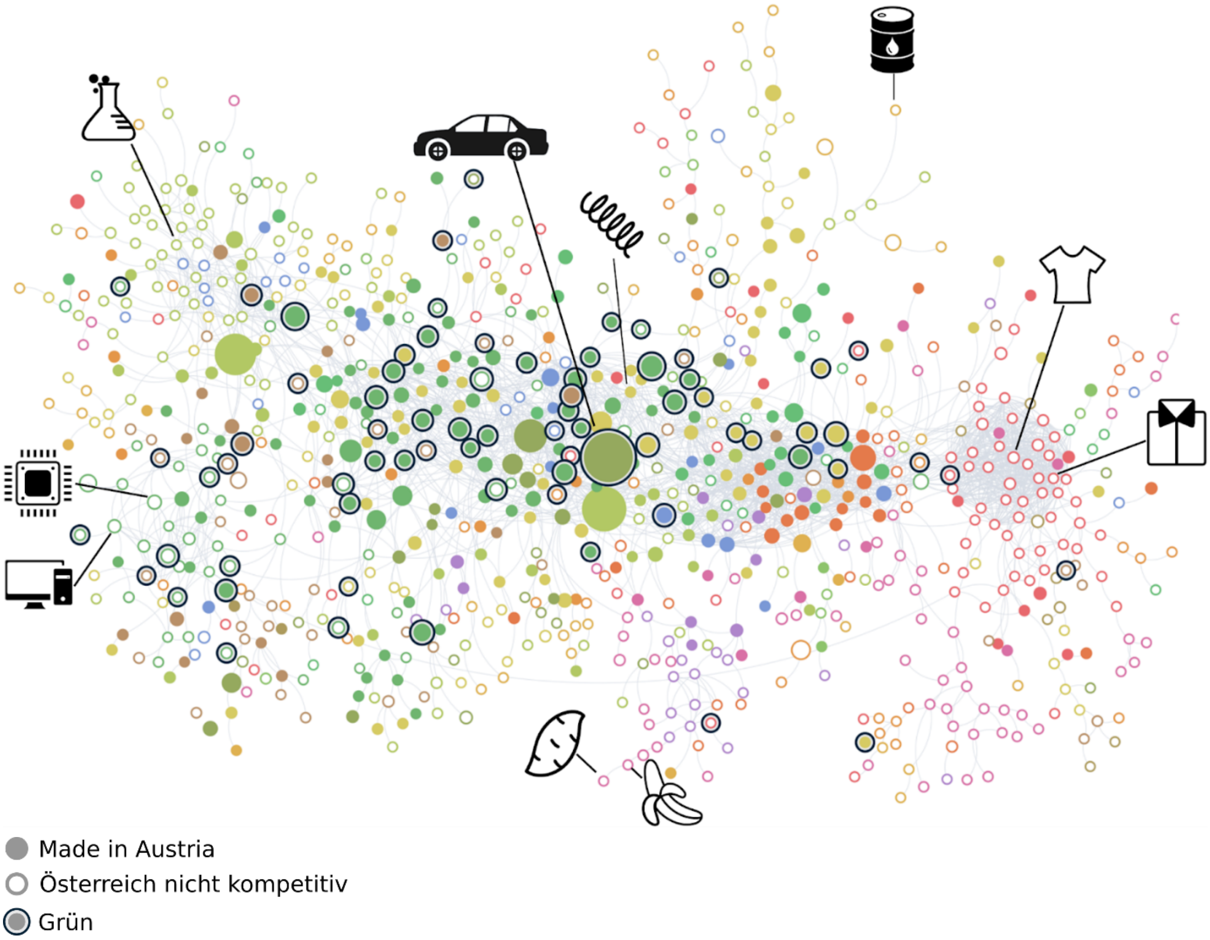

Fig. 5. *The Product Space visualizing the products Austria already produces competitively and the green products identified by international trade organizations. Both green and the products Austria already produces are found in the central region of the Product Space. It is also evident that Austria already produces a large proportion of green products competitively, which is reflected in Austrias high position (4th) in the Green Complexity Index (GCI) ranking.*

The Green Adjacent Possible

To identify green products that are not yet (competitively) produced but for which an economy would have the necessary capabilities, following Mealy & Teytelboym (2020) [4], we introduce the concept of the "Green Adjacent Possible" (GAP). The GAP consists of the set of products that we identify as green diversification opportunities. We construct the GAP using the following steps. First, we calculate the Product Space density i for all products i that are currently not competitively exported, i.e. $RCA_i<1$. Second, we only want to consider products which are close to the current export basket. Therefore, we only keep products with i>0.4. The threshold corresponds to the median i of all currently not produced green products. Third, we only consider green products, as defined by the WTO, OECD and APEC lists mentioned before. Please note that we define the GAP slightly differently than Mealy & Teytelboym (2020) [4]; restricting our analysis to the closest few products allows us to analyze the GAP in greater detail.

Austria's opportunities for new green products

In Fig. 6 only green products are shown in color. The GAP is highlighted by two outlines around the respective nodes. Austria's GAP consists of the nodes most adjacent to Austria's current export portfolio.

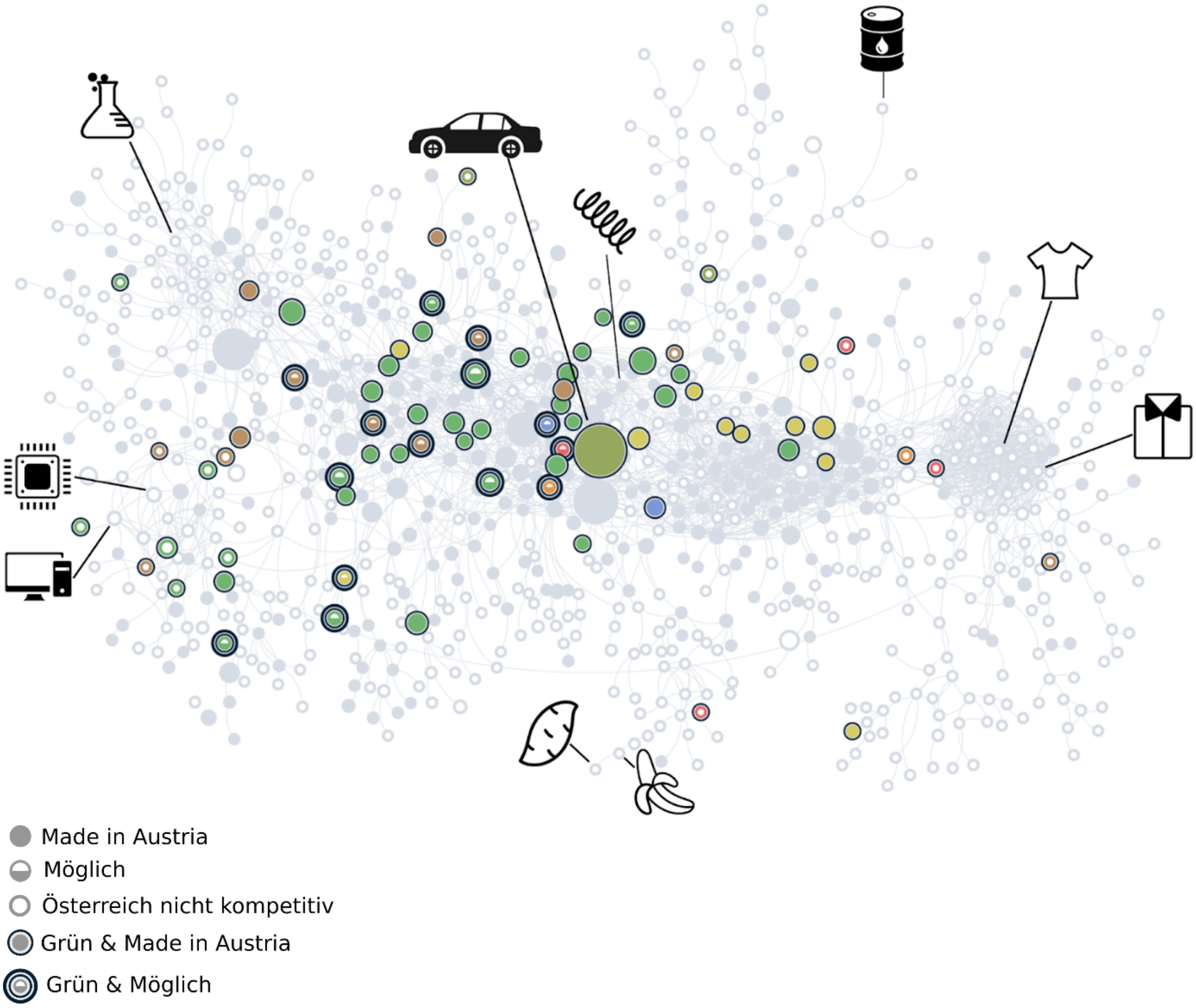

Fig. 6. *Austrian and green products in the Product Space. Only green products are highlighted in this figure. A product that is competitively produced in Austria is indicated by a filled node. If a product is not produced and dissimilar to Austria's current export basket, it is shown as an empty node. If a product is not produced, but similar to Austria's current exports, it is shown as a half-filled node. The GAP is highlighted by two rings around the node.*

In Tab. 2 we show the ten products with the highest Product Space density in the GAP. The first column names the product, the second column, named “Ex-Out”, specifies which subgroup of the HS-category that are viewed as green, and the third column describes the product’s environmental benefit. Most products in the GAP belong to the Machinery (57%) or the Miscellaneous (27%) chapters of the HS-classification. The top three products ranked by Product Space density all have environmental benefits relating to wastewater treatment or reduction. Another five products in the top ten products relate to green energy production or the reduction of energy consumption. For the full list of products in the GAP we refer to the dashboard accompanying this report (https://ecto.rfte.at/), described in a later section of this report.

	Product description	**Ex-Out**	**Environmental benefit**
1.	Pumps for liquids	Optional ex-out may include: Pumps for sewage and wastewater treatment.	For handling and transport of wastewater or slurries during treatment.
2.	Appliances for thermostatically controlled valves	-	For handling and transport of wastewater or slurries during treatment.
3.	Sanitary ware and parts of iron or steel	Water saving shower. Water closet pans and flushing cisterns/urinals including dry closets.	Water conserving showers (provided with a specific water-efficiency shower head) and dry closets (operating on the basis of composting) are designed to conserve water.
4.	Nonwoven textiles	Landfill drainage mats, Fabric of polyethylene, polypropylene, or nylon for filtering wastewater, Filter cloth (PE, PP, Nylon) Filter bag (sleeve).	Used to ensure efficient leachate or gas landfill drainage.
5.	Thermometers, hydrometers etc.	-	Carbon Capture and Storage, Efficient Consumption of Energy Technologies
6.	Amino-resins	-	Carbon Capture and Storage, Efficient Consumption of Energy Technologies
7.	Automatic regulating instruments	Optional ex-outs may include: Heliostats, temperature sensor for solar boiler/water heater; Differential temperature controller for solar boiler/water heater.	Products include thermostats that control the efficiency of air conditioning, refrigeration or heating systems.

8.	Pumps, compressors, fans, etc.	Industrial hoods for transportation or extraction of air pollutants such as exhaust gas or dust.	Air handling equipment. Used in a number of environmental applications, e.g. flue gas desulphurisation (the process by which sulfur is removed from combustion exhaust gas).
9.	Gas turbines	-	Gas turbines for electrical power generation from recovered landfill gas, coal mine vent gas, or biogas (clean energy system). Note that these turbines do "not exceed 5,000 kW".
10.	Steam boilers	Biomass boilers	Boilers for the production of heat and power on the basis of (renewable) biomass fuels.

Tab. 2. *Products in Austria's Green Adjacent Possible, ranked by Product Space density. The first column contains the product description, the second column "Ex-Out" contains an optional specification provided by the WTO and the third column explains the environmental benefits of the green product.*

Comparison of complexity and market size of products in the GAP

Ranking products in the Green Adjacent Possible by their Product Space density reveals which products it would be easiest for Austria to venture into. However, it does not reveal how attractive the product would be to venture into. We explore this by rearranging the products in the GAP by two economically relevant dimensions. On the one hand we discuss the complexity of the products quantified by the Product Complexity Index (PCI). A complex product requires many and rare capabilities and is therefore hard to produce; we expect lower global competition and higher profits for more complex goods. On the other hand, we discuss the global market size for the products proxied by the global export volume. If a good is commonly exported, we can assume that there is a large demand for it. The PCI and world-market size is provided along with the international trade data by Harvard's Growth Lab [8].

Tab. 3 shows the three rankings side by side. Apparently the rankings are positively correlated, however, the list gets rearranged to some extent by applying different rankings. Some products that are not in the top 10 density products appear in the top PCI or world-market size rankings.

Rank	Density	PCI	World-market size
1.	Pumps for liquids	Appliances for thermostatically controlled valves	Appliances for thermostatically controlled valves
2.	Appliances for thermostatically controlled valves	Pumps for liquids	Pumps for liquids
3.	Sanitary ware and parts of iron or steel	Instruments for measuring properties of liquids or gases	Pumps, compressors, fans, etc.
4.	Nonwoven textiles	Pumps, compressors, fans, etc.	Electric heaters
5.	Thermometers, hydrometers etc.	Automatic regulating instruments	Automatic regulating instruments
6.	Amino-resins	Amino-resins	Gas turbines
7.	Automatic regulating instruments	Other parts for machines and appliances	Instruments for measuring properties of liquids or gases
8.	Pumps, compressors, fans, etc.	Nonwoven textiles	Amino-resins
9.	Gas turbines	Thermometers, hydrometers etc.	Glass fibers
10.	Steam boilers	Water gas generators	Nonwoven textiles

Tab. 3. *The top ten green products Austria does not yet produce with respect to their Product Space density in Austria, their Product Complexity Index (PCI) and their world market size measured as total export volume.*

We identify the most attractive products by locating the products of the GAP in the PCI-export volume plane in Fig. 7. We are interested in high PCI - high global export volume products, located in Fig. 7 in the top right corner. For those products we expect less competition but large demand. The blue lines in Fig. 7 denote the median of the respective value and split the PCI-export volume plane into four quadrants. The products in the high PCI - high global export volume quadrant are listed in Tab. 3.

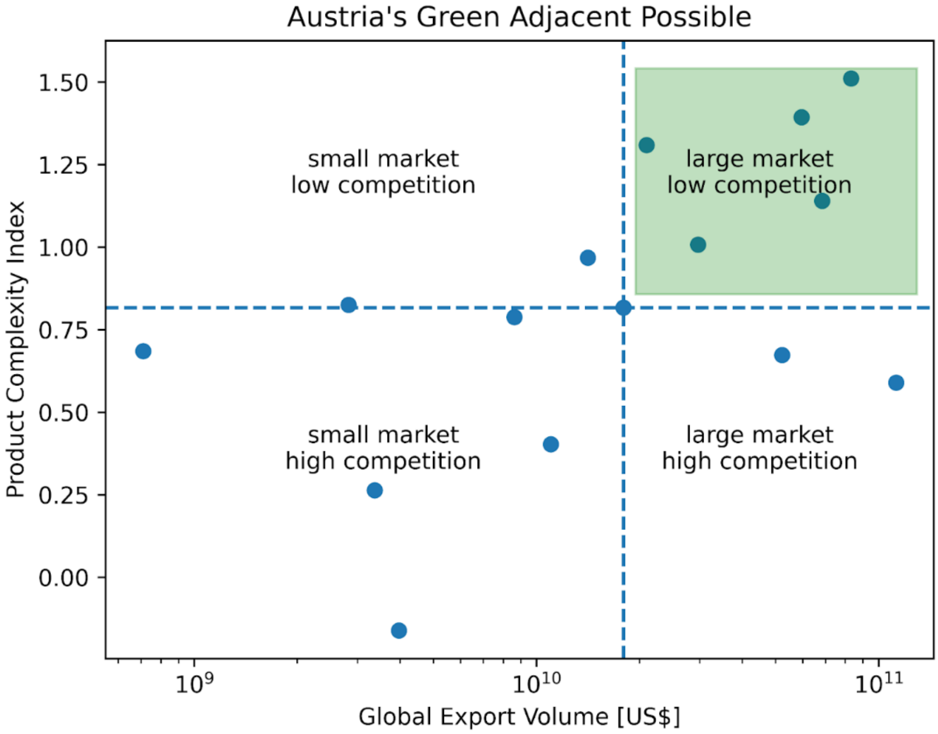

Fig. 7. *Scatter plot of products in the GAP, with the product's global export volume on the x-axis and its PCI on the y-axis. The blue dashed lines mark the median value of the respective axis and separate the export-volume-PCI plane into four quadrants. The top right corner with a large market size and high-PCI contains the most attractive products.*

Product	**PCI**	**Global Export Volume [$]**
Automatic regulating instruments	1.01	2.97×10^{10}
Pumps for liquids	1.39	6.02×10^{10}
Pumps, compressors, fans, etc.	1.14	6.89×10^{10}
Appliances for thermostatically controlled valves	1.51	8.37×10^{10}
Instruments for measuring properties of liquids	1.31	2.10×10^{10}

Tab. 4. *Products in the high PCI - high global export volume quadrant in Fig. 7. These products are identified as the most attractive green diversification opportunities for Austria.*

Preconditions and risks

Based on the results of the first work package, we analyze the prerequisites and risks for market entry and economic growth in the identified product groups. To enable the derivation of concrete RTI recommendations, the results of work package 1 are analyzed with regard to material consumption, economic geography and international context. The following results are obtained:

- The identified products are evaluated with respect to the demand for critical materials (e.g. rare earths), respectively their origin.
- The product groups identified in work package 1 are discussed broken down by regions in Austria.
- The central elements of the study will also be carried out for two comparative countries in order to discuss the results in an international context.

Materials used for GAP products

We analyze the materials used for the five product groups in the top right quadrant of Fig. 7. These products are the most attractive in terms of their market situation, since there exists a large global market for these products and competition is comparatively low. They also display the highest PCIs and therefore rank among the most complex GAP products. The usage of scarce or critical materials is therefore most likely for these product groups.

The “Final List of Critical Minerals 2022” [15] published by the International Energy Agency in 2022 provides an overview of critical minerals. The minerals listed are characterized as critical minerals by the US government, because they are of great importance for economic development and are prone to supply disruptions. We discuss the likelihood of the identified GAP product groups to contain these materials.

Automatic regulating instruments

Products, such as thermostats that regulate the room temperature to save energy are part of this product category. Nowadays, thermostats are mostly digital devices and rely on thermistors which is a type of temperature sensitive resistor to measure the temperature. Thermistors can be made of different metals, such as chromium, cobalt, iron, manganese or nickel [16]. Even though all of these metals except for iron are deemed critical, the amount of metal needed for each thermostat is very small. The possibility of manufacturing thermistors from different metals leads to a high substitutability among those metals and a low risk of a significant supply shortage. Modern thermostats also use LCD screens as user interfaces which contain the scarce element indium.

Pumps for liquids

Products with an environmental benefit from this product category are mainly used for handling and transporting wastewater or slurries during treatment in waste management. Pumps are mostly made of common materials such as cast iron, bronze or steel [17] which are not considered to be critical .

Pumps, compressors, fans, etc.

Products with an environmental benefit from this product category are mainly used for transporting and cleaning air or other gasses in industrial processes. Less complex products such as fans or simple pumps are mostly made of common materials such as iron, steel or aluminum. More complex products in this category such as vacuum pumps sometimes contain more scarce materials such as titanium, indium, tungsten, tantalum or molybdenum [18]. These critical materials are used for vacuum pumps with high temperature applications or for especially high-quality vacuums.

Appliances for thermostatically controlled valves

Products with an environmental benefit from this product category are mainly used for handling and transporting wastewater or slurries during treatment in waste management. These valves are made of common materials such as iron or steel which are not considered to be critical.

Instruments for measuring properties of liquids

Products with an environmental benefit from this product category are mainly used for checking the flow, level, pressure or other variables of liquids, for example in wastewater treatment. Products like flow meters, level gauges, manometers or heat meters are included in this category. There are mechanical, electrical and digital variants for each of these products. Therefore a general assessment of the materials used is not possible. Digital variants of these products use similar materials like other digital measurement devices such as indium for LCD screens.

Discussion of critical materials used for GAP products

Tab. 5 provides an overview of identified critical minerals that might be used for the five most complex GAP products that have the largest world market. The main country of origin is listed to discuss possible monopoly positions of certain countries and geopolitical implications.

The top five identified GAP products for Austria are mostly measurement and handling devices for waste streams and wastewater. There are mechanical, electrical and digital variants for many of these products. Digital products and products for special applications, such as high temperature vacuum pumps, tend to use more critical minerals for which security of supply, recycling opportunities and geopolitical implications have to be considered. Reserves for critical minerals are distributed unevenly across the globe which leads to a strong monopolization of production of these minerals. China is the leading producer of Indium, Tungsten and Molybdenum whereas South Africa takes the lead in Chromium and Manganese production. In order to become resilient towards possible supply shocks, potential manufacturers of these GAP products should carefully observe the world market situation of these critical materials. The manufacturing of non-digital variants of these GAP products should also be considered, at least for applications and customers for which digital versions are not absolutely necessary.

Critical Mineral	GAP product groups	Main country of origin [19]
Indium	Automatic regulating instruments, Pumps, compressors, fans, etc., Instruments for measuring properties of liquids	China (>50% of global production)
Chromium	Automatic regulating instruments	South Africa (>40% of global production)
Manganese	Automatic regulating instruments	South Africa (>35% of global production)
Cobalt	Automatic regulating instruments	Kongo (~70% of global production)
Nickel	Automatic regulating instruments	Indonesia (>35% of global production)
Tungsten	Pumps, compressors, fans, etc.	China (>80% of global production)
Tantalum	Pumps, compressors, fans, etc.	Congo (>30% of global production)
Titanium	Pumps, compressors, fans, etc.	Germany (>50% of global production)
Molybdenum	Pumps, compressors, fans, etc.	China (>40% of global production)

Tab. 5. *Critical minerals, GAP products that might contain them and their main country of origin.*

Green opportunities and Austrian regions

In this section we answer two questions. First, in which Austrian regions are the capabilities located to produce the goods identified in the GAP? Second, do we find different products in the GAP for different regions, given they have different productive capabilities?

Because there is no regionalized or firm level export data available for Austria, we use Structural Business Statistics (SBS) provided by the Austrian Statistics Office [20]. The SBS contains information on the number of establishments, employees, and revenues aggregated to NACE rev. 2 4-digit industry codes. Geographically, the data is available for NUTS-2 regions, equivalent to Austrian federal states. We use the SBS for the latest available year, 2020.

There is no direct correspondence table between HS 2012 (at the 4 digit level), and NACE rev. 2 available. For this reason, we used a mapping that proceeded across multiple steps, building a chain of one-to-one correspondence tables starting from the HS 2012 code to the desired NACE rev. 2 nomenclature. On the whole, the chain is composed of the following six nomenclatures: HS 2012, SITC rev. 3, ISIC rev. 3, ISIC rev. 3.1., NACE rev. 1.1, NACE rev. 2. The correspondence tables were downloaded from Eurostat's website "Reference and Management of Nomenclatures" [21] and were merged together. Once we established the path between the two nomenclatures, we identified which HS codes were grouped in which NACE rev. 2 codes. Across all products, a total of 1109 HS 2012 codes were mapped to 282 NACE rev. 2 codes. When considering the environmental goods alone, 133 HS 2012 codes were linked to a total of 154 NACE rev. 2 codes.

Using the crosswalk from HS to NACE we map the products identified in the GAP to industries. Then we look in which Austrian region these industries have the highest RCA, respectively. In Fig. 8 we show two examples. Fig. 1a shows that firms with the capabilities to produce "Pumps for liquids" (HS8413) are located mostly in Tyrol and Upper Austria. Fig. 1b shows that firms with the capabilities to produce "Nonwoven textiles" (HS5603) are mostly located in Vorarlberg and Salzburg.

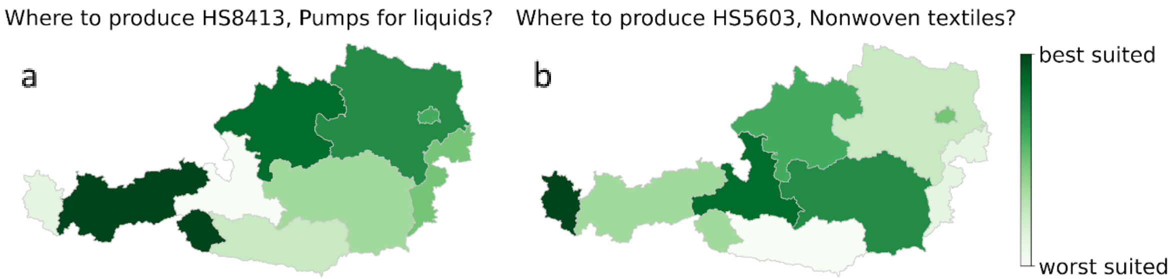

Fig. 8. *Regional potential to produce a given good. (a) Tyrol has the best capabilities to produce "Pumps for liquids", followed by Upper Austria and Lower Austria. (b) Vorarlberg has the best capabilities to produce "Nonwoven textiles", followed by Salzburg and Styria.*

In Tab. 6 we show the top three best suited regions for the top ten products in the GAP. Green capabilities seem to be located strongly in the west of Austria, Tyrol is the best suited region for four products, followed by Vorarlberg and Styria (two each) and Salzburg and Lower Austria (one each). Although Upper Austria is not the most well suited region for any of the shown products, it has many green capabilities as displayed by four second ranks. For Burgenland and Carinthia we find one and zero mentions in Tab. 6. The industrial structure of these regions is comparably less well suited for green products. For a closer inspection, we provide the results to these calculations for every product in a dashboard, described in the Section "Work package 3" of this report.

	Product description	Best suited regions
1.	Pumps for liquids	1. T 2. OÖ 3. NÖ
2.	Appliances for thermostatically controlled valves	1. Tyrol 2. OÖ 3. NÖ
3.	Sanitary ware and parts of iron or steel	1. VBG 2. NÖ 3. T
4.	Nonwoven textiles	1. VBG 2. SBG 3. STMK
5.	Thermometers, hydrometers etc.	1. STMK 2. VBG 3. VIE
6.	Amino-resins	1. NÖ 2. OÖ 3. STMK
7.	Automatic regulating instruments	1. STMK 2. VIE 3. VBG
8.	Pumps, compressors, fans, etc.	1. T 2. OÖ 3. STMK
9.	Gas turbines	1. T 2. VBG 3. NÖ
10.	Steam boilers	1. SBG 2. T 3. BGLD

Tab. 6. *Best suited regions for the top ten identified products. The abbreviation codes are Tyrol (T), OÖ (Upper Austria), NÖ (Lower Austria), VBG (Vorarlberg), SBG (Salzburg), STMK (Steiermark), VIE (Vienna), BGLD (Burgenland).*

Based on the industries in a region we can use the crosswalk described above to generate a virtual product portfolio for every region. For these virtual export baskets we perform the same steps as described in the previous section and construct a regional GAP. Tab. 7 shows the results for Vienna and Vorarlberg. Due to the different set of industries present in Vienna and Vorarlberg, their GAPs contain diverging sets of products. For example, the top three products for Vienna are “Dish washing machines”, “Lamps” and “Other lifting machinery”. For Vorarlberg the top three products are “Other lifting machinery”, “Other engines and motors” and “Sanitary ware and parts of iron or steel”. The regionalized Product Spaces and GAPs can be explored using the interactive online visualization provided along with this report.

	Vienna	**Vorarlberg**
1.	Dish washing machines	Other lifting machinery
2.	Lamps	Other engines and motors
3.	Other lifting machinery	Sanitary ware and parts of iron or steel
4.	Instruments for physical or chemical analysis	Parts suitable for use with spark-ignition engines
5.	Structures and their parts, of iron or steel	Other articles of iron or steel
6.	Thermometers, hydrometers etc.	Instruments for physical or chemical analysis
7.	Automatic regulating instruments	Nonwoven textiles
8.	Measuring instruments	Other cast articles of iron or steel
9.	Machinery for working minerals	Aluminum containers, <300 liters
10.	Self-propelled bulldozers, excavators and road rollers	Tanks etc. < 300 liters, iron or steel

Tab. 7. *Regional GAPs for Vienna and Vorarlberg.*

International comparison

To put our results into context, we compare Austria’s GAP with Switzerland and Germany, two other countries with similar economic structure.

Austria’s GDP in 2020 was 379 billion Euro and its export volume was ca. 200 billion Euro. In Fig. 9 we show the composition of exports for Switzerland. Switzerland is comparably large to Austria with a GDP of 667 billion Euro and an export volume of 379 billion Euro. Albeit its comparable size, it has quite a different economic structure. Its main exports are chemicals, which to a large extent consists of medicaments, serums and vaccines, and traded raw materials like gold and other precious metals. The third largest block is machinery.

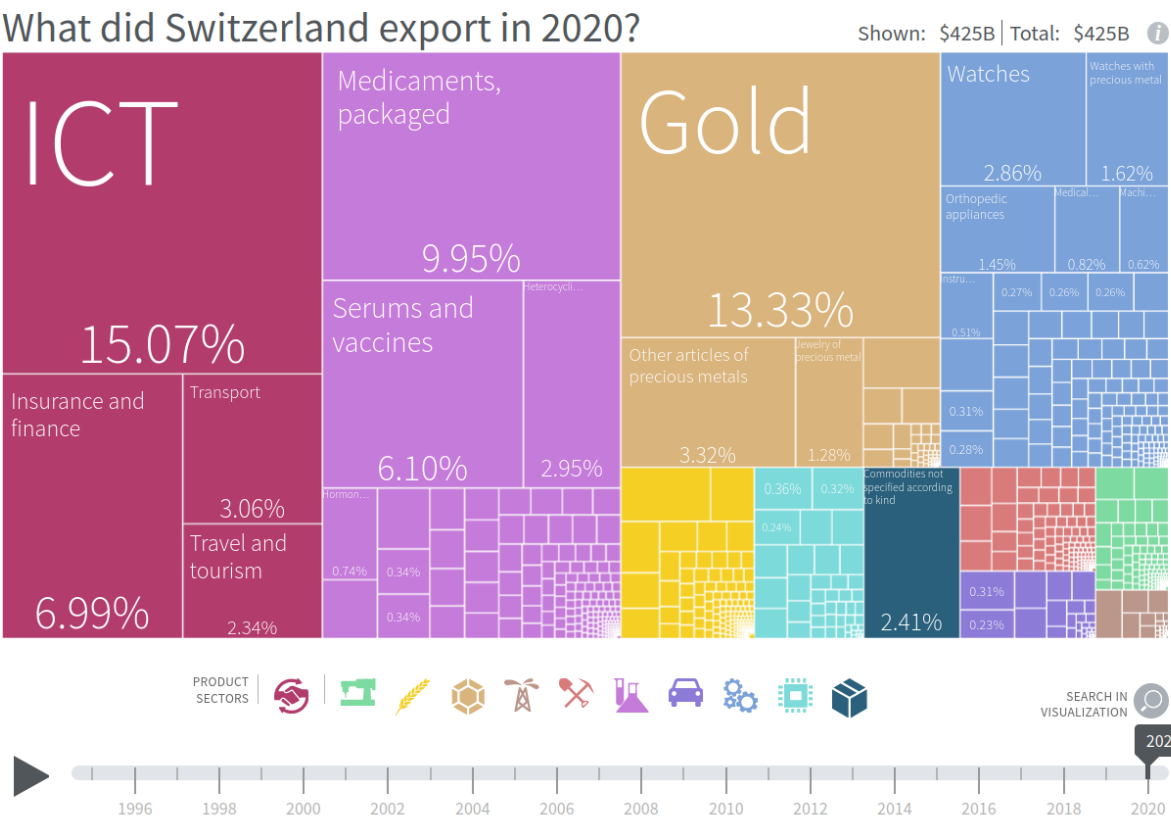

Fig. 9. *Swiss exports of the year 2020 visualized as a tree map. Apart from services (dark red), Switzerland mostly exports chemical products (violet), minerals (brown-gold) and machinery, such as watches (dark blue). Source:* *https://atlas.cid.harvard.edu/* *[8]*

Germany is significantly larger than Austria, with a GDP of 3,398 billion Euro and an export volume of 1,517 billion Euro, see Fig. 10. In its economic structure it is much more similar to Austria than Switzerland. Its main exports is machinery, followed by chemicals, cars and car parts. Further, it is the main export and import partner of Austria and it is instructive to compare to its GAP.

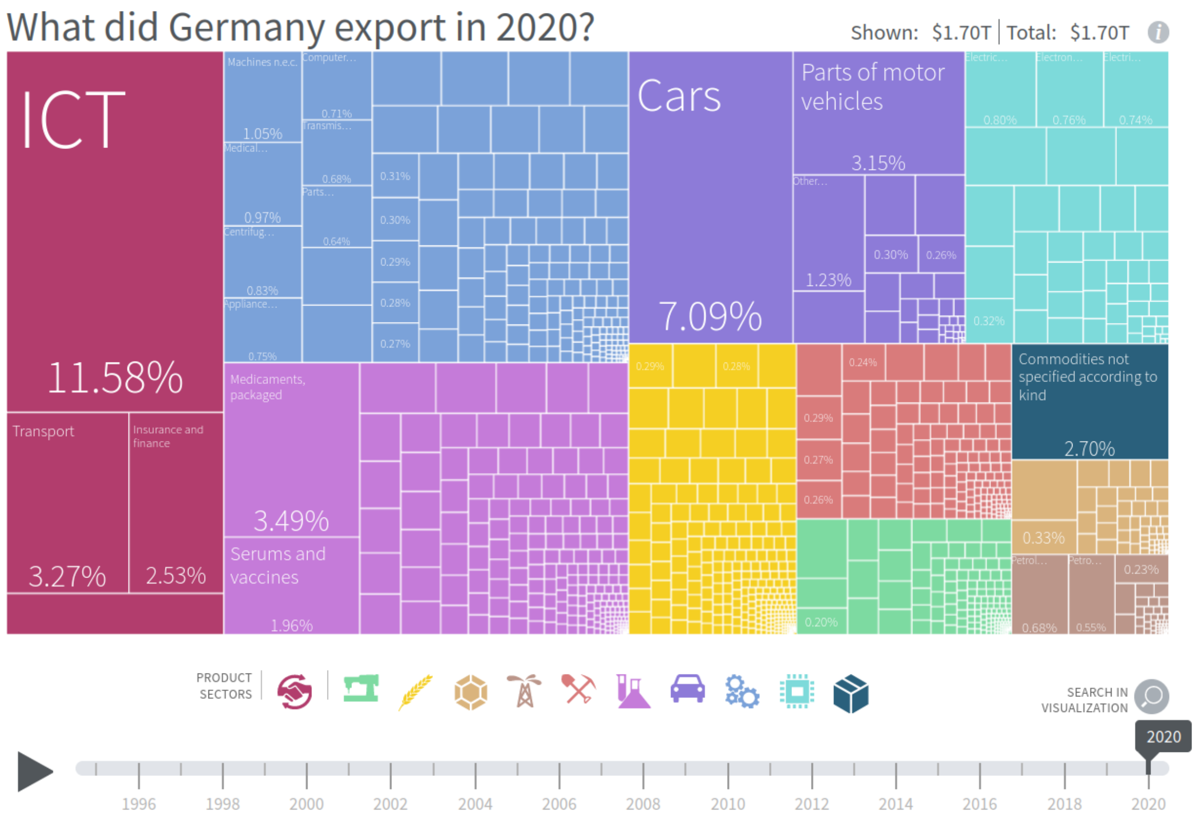

Fig. 10. *Germany's exports of the year 2020 visualized as a tree map. The dominance of machinery (light blue) and cars (dark blue) is clearly visible. Source: https://atlas.cid.harvard.edu/ [8]*

Tab. 8 shows the list of density-ranked green products for Austria, Switzerland, and Germany. The GAPs overlap for a few products, but are in general quite different. Germany's highest potential green diversification opportunities contain products relating to the energy sector and electrical equipment such as Lamps or Electrical machines. Switzerland's top 5 opportunities notably contain two product categories relating to the measurement of physical quantities.

	Austria	**Germany**	**Switzerland**
1.	Pumps for liquids	Gas turbines	Gas turbines
2.	Appliances for thermostatically controlled valves	Water gas generators	Electromagnets
3.	Sanitary ware and parts of iron or steel	Lamps	Thermometers, hydrometers etc.
4.	Nonwoven textiles	Electrical machines with individual functions n.e.c.	Instruments for measuring electricity

5.	Thermometers, hydrometers etc.	Glass fibers	Pumps for liquids
6.	Amino-resins	Buses	Transmission shafts
7.	Automatic regulating instruments	Tubes of cast iron	Centrifuges
8.	Pumps, compressors, fans, etc.	Auxiliary parts for use with boilers	Self-propelled bulldozers, excavators and road rollers
9.	Gas turbines	Air conditioners	Electrical machines with individual functions n.e.c.
10.	Steam boilers	Tanks etc. > 300 liters, iron or steel	Water gas generators

Tab. 8. *Comparison of the GAP rankings of Austria, Germany and Switzerland.*

We want to note two general observations. First, every country has its very specific GAP, even if the economic structure is relatively similar. Second, there are two reasons for diverging GAPs. Different proximities of the current export basket to green products result in different rankings. Also, if country A already exports one or several products of country B's GAP competitively, these products are not listed in the GAP of country A anymore.

Communication of the results

The results of the study are presented and documented accordingly to enable meaningful communication and dissemination of the study results. The deliverables in this work package are:

- An interactive online visualization of the results.
- A presentation of preliminary results as part of the event "Innovation im Zeichen der Kreislaufwirtschaft" in Alpbach on August 24th, 2022. (Not further documented.)
- Presentation of the final results at the event "Transformative Potenziale freisetzen", organized by RFTE November 4th, 2022.
- Preparation of the final written report at hand. (Not further documented.)

Interactive online visualization

To make this research accessible to stakeholders and the general public, we developed a dashboard. The ECTO-dashboard can be accessed at https://ecto.rfte.at/. Fig. 11 shows the dashboard and explains the different elements of the visualization.

It also allows the exploration of the different products, see Fig. 12, and of the regional analysis, see Fig. 13.

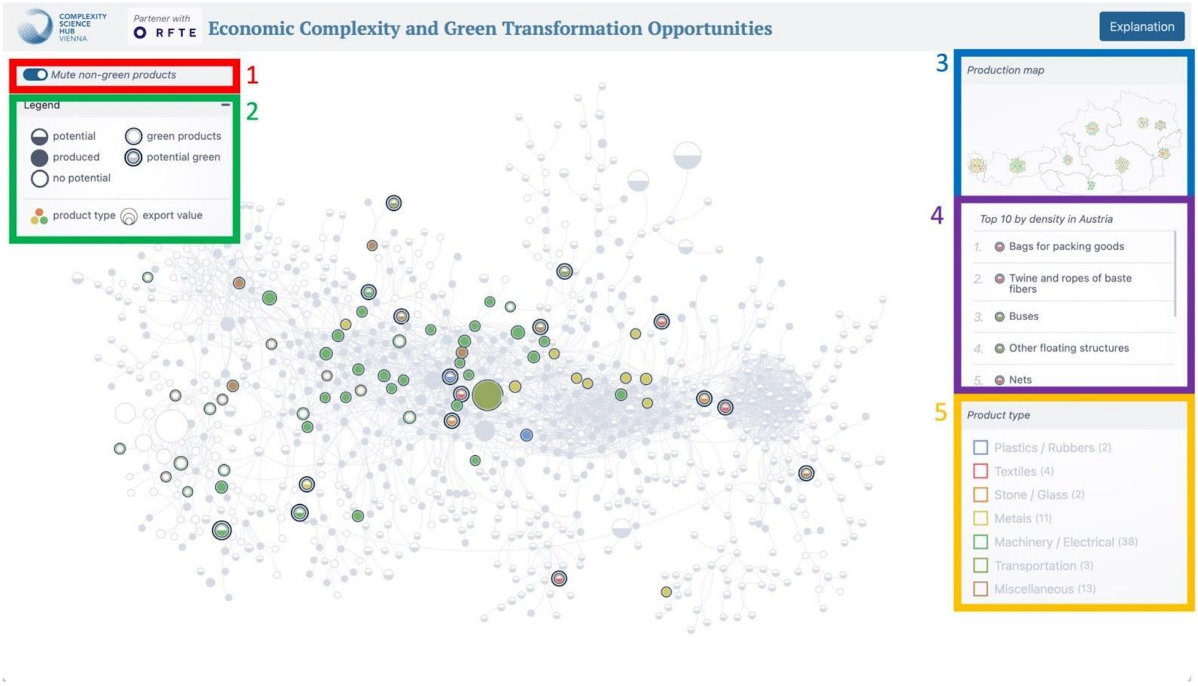

Fig. 11. *Dashboard which shows the Product Space. (1) Allows to mute the non-green products, this greys out the non-green product, leaving only the green ones highlighted in color. (2) The legend describes how the different product classes are differentiated. Green products have a black frame, and depending whether the product is already produced, has potential in Austria or is not produced and has no potential, the dot is either full, half full or empty. (3) A map of Austria with its federal states. The user can click on the different federal states to highlight only the products which are produced competitively in each respective state. (4) Top 5 potential green products in Austria (or the respective federal state) according to their Product Space density. (5) Allows to only highlight one specific product category.*

Fig. 12. *Hovering over one specific product highlights only the product itself, and its neighbors/the products which are connected to it in the Product Space. Clicking on it reveals some additional information about the product on the right. This includes the description and reasoning why the product is classified as a green product (1), the a ranking of the federal states where the product is produced, and the ones where it is produce competitively are highlighted (2) and the linked green and non-green products (3).*

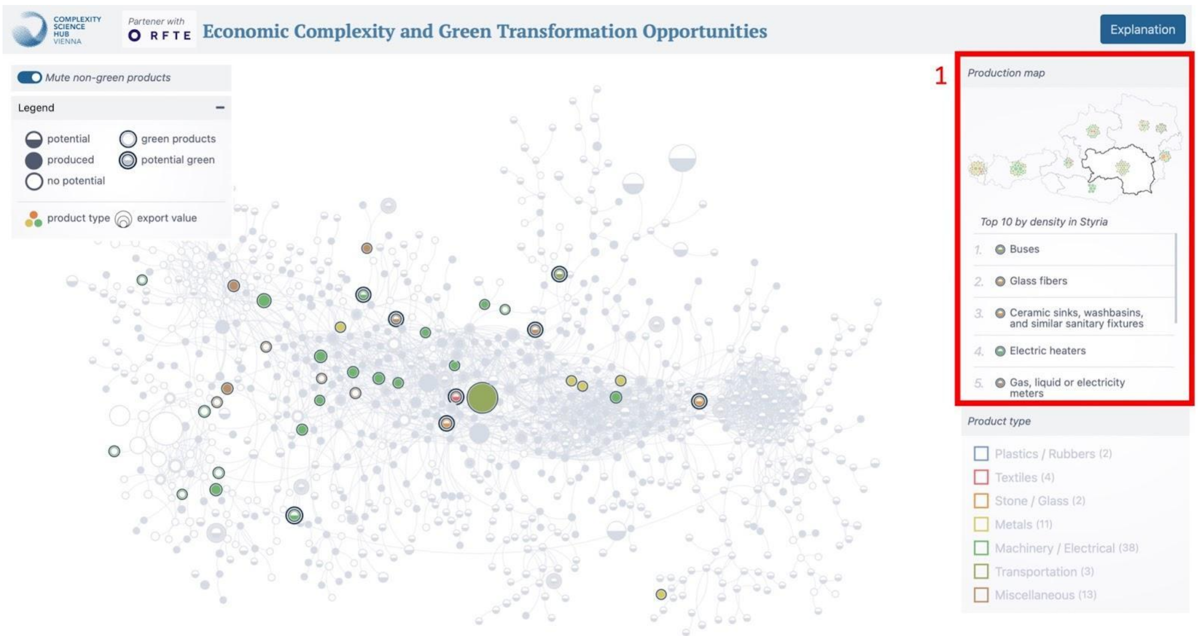

Fig. 13. *Clicking on one federal state in the map on the right (1) highlights only the green products which can be produced competitively in that state. The potential green products are listed below according to their Product Space density.*

Conclusion

In this exploratory study, we determine Austria's green diversification opportunities by identifying green products that are closest to Austria's current position in the Product Space. In particular, we identify a list of green products that are not yet competitively produced in Austria based on the work on green Economic Complexity by Mealy & Teytelblom [4]. We find that Austria already exports 41 of 75 green products competitively. To establish future export opportunities, we identify Austria's Green Adjacent Possible (GAP). Among the identified products there are several of high complexity and large global trade volumes. We identify a set of five products that unite high product complexity, low expected competition and a large global market.

We analyze the products listed in Tab. 4 for their dependence on critical materials to further assess their feasability. We find that "Automatic regulating instruments", "Pumps, compressors, fans, etc." and "Instruments for measuring properties of liquids" might contain some critical minerals like

Indium, Chromium or Cobalt whose scarce supply is controlled by just a few countries. In the case of "Automatic regulating instruments", like thermostats, there is a range of possibilities to substitute specific critical minerals needed. In the "Pumps, compressors, fans, etc." product category, only vacuum pumps with very specific applications are prone to contain critical minerals. In order to be resilient towards possible supply shocks, potential manufacturers of these GAP products should carefully observe the world market situation of the critical minerals needed and explore recycling opportunities. The manufacturing of non-digital variants of these products should also be considered, as those tend to contain less critical materials.

We further identify the Austrian federal states which are best suited to produce the identified green products, according to their regional industrial capabilities. States such as Tyrol, Vorarlberg and Styria are expected to have a competitive advantage to produce the identified green products, whilst Burgenland and Carinthya are disadvantaged. To put our results into an international context we compare Austria's GAP with the respective GAPs of Switzerland and Germany. We find different rankings and a set of overlapping and diverging products, reflecting the different set of capabilities present in these countries as well as their differing export baskets.

To make the results of the study easily accessible, we publish a dashboard that allows users to interactively explore Austria's Green Adjacent Possible. The ECTO-dashboard is published under: https://ecto.rfte.at/

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