Leiden-Delft-Erasmus
Centre for Sustainability Circular Industries Hub

CRITICAL MATERIALS, GREEN ENERGY AND GEOPOLITICS: A COMPLEX MIX

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Introductie:

NEDERLANDSE SAMENVATTING

Grondstoffen, groene energie en geopolitiek: een gecompliceerde mix

De Europese Unie heeft met de Green Deal ambitieuze en broodnodige klimaatdoelen geformuleerd. Hierbij moet de netto uitstoot van broeikasgassen tegen 2050 tot nul zijn teruggebracht zonder uitputting van grondstoffen en met oog voor het welzijn van mensen en regio's.

Natuurlijk vergt het behalen van deze doelen de nodige technische innovaties. Maar eerst en vooral is de Green Deal een transitie van fossiele brandstoffen naar metalen – zoals ijzer, koper, lithium en een scala aan zeldzame aardmetalen die nodig zijn voor de productie van de benodigde windturbines, zonnepanelen, elektrolytische cellen, accu's, enzovoort.

Dat maakt deze metalen tot kritieke materialen voor het slagen van de energietransitie, waarbij Nederland, en de EU in het algemeen, op dit moment vrijwel geheel afhankelijk is van aanvoer vanuit andere landen.

In deze whitepaper uiten onderzoekers van de Leiden-Delft-Erasmus-universiteiten hun bezorgdheid over de realisatie van de energietransitie in de huidige geopolitieke context.

Ze delen hun perspectief over de (on)toereikendheid van de markt en de werkelijke financiële en sociale kosten van het bereiken van grondstof-onafhankelijkheid.

Ze benadrukken de urgentie tot actie om een impasse te voorkomen, waarbij ze lessen uit het verleden, mogelijkheden tot grondstofcirculariteit, en een nieuwe financiële zienswijze aandragen als mogelijke oplossingen voor het bereiken van onze groene doelen.

Kortom, hoe we er op dit moment als Nederland en EU voor staan wat betreft de benodigde kritieke materialen, en hoe we tot een sterke en onafhankelijke basis voor de energietransitie kunnen komen.

Voor deze paper zijn geinterviewd:

Dr. Rene Kleijn
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Universiteit Leiden
Dr. Benjamin Sprecher
Faculteit Industrieel Ontwerpen
TU Delft
Dr. David Peck
Faculteit Bouwkunde TU Delft
Dr. Jojo Nem Singh
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Prof. dr. Ester van der Voet
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Alle interviews zijn ook in het Nederlands te lezen op **www.leiden-delft-erasmus.nl** in het **Kennisdossier Kritieke Materialen & Energietransitie**.

Critical materials, green energy and geopolitics:

a complex mix

Introduction:

WITH THE CLIMATE CRISIS ALL BUT A REALITY, THE EUROPEAN UNION HAS FORMULATED AN AMBITIOUS GREEN DEAL AIMING TO ENSURE:

- **NO NET EMISSIONS OF GREENHOUSE GASES BY 2050**
- **ECONOMIC GROWTH THAT IS DECOUPLED FROM RESOURCE USE**
- **NO PERSON AND NO PLACE LEFT BEHIND**

INTRODUCTION

Raw materials are at the heart of this Green Deal: metals such as iron, copper and lithium as well as a vast array of rare earth metals will be replacing coal, oil and natural gas.

The energy transition, all the more urgent now that the EU wants to become independent of Russian gas, is a monumental undertaking that stretches global supply chains. Conversely, global supply chain disruptions can seriously affect the energy transition.

In this whitepaper, researchers from Leiden-Delft-Erasmus Universities share their perspective on the global dependencies and geopolitical aspects that play a role in acquiring the much-needed raw materials to achieve the energy transition – how we got where we are now, and how we can reduce our dependencies going forward.

Take home messages:

1. The energy transition is a switch from fossil fuels to metals.

2. The EU will have to build its own (urban) mining and refining operations to decrease its raw materials dependency.

3. The EU will need to foster the materials that will accumulate in the energy infrastructure in the coming decades.

Photo Pexels

RENÉ KLEIJN

Associate professor in Industrial Ecology and one of initiators of this whitepaper

Photo Barbra Verbij

Institute of Environmental Sciences (CML) of Leiden University

For associate professor **René Kleijn** time is the scarcest resource when it comes to halting climate change. "The latest report by the Intergovernmental Panel on Climate Change, the IPCC, states that greenhouse gas emissions must peak by no later than 2025," he says. "This calls for a monumental effort, requiring decisive political action and huge investments in renewables, starting now."

Next to bringing down emissions, this transition will, in the long run, free us from our dependence on coal, gas and oil. "The transition to wind, solar, hydrogen and batteries involves a fundamental switch from continuous mining of fossil fuels towards fostering a stockpile of wind turbines and solar panels," Kleijn explains.

The energy transition: a monumental shift in recources and policies

Interview with Dr. Rene Kleijn

"In its essence, it is a shift from fossil fuels to metals. It requires a massive shift in mining – from coal, oil, and natural gas to metals – to build-up this stockpile in the next thirty years."

RAW MATERIALS

Much of Kleijn's research is about resource scarcity and global supply chains – charting global resource supply chains for coal, nickel, and rare earth metals, analysing where mines are located, who owns them, which countries or companies do the refining, and studying the ownership structures of big industry players. "We will need huge amounts of steel to build the wind turbines, and neodymium for the magnets that will replace the high-maintenance gear box," he says. "We will also need large quantities of copper for cables, nickel and lithium for making batteries, and we have to produce a lot of solar panels based on a variety of materials including silicon, silver, indium and tellurium."

According to Kleijn, there is no shortage in the ores that need to be mined. The problem is for supply to keep up with rapidly increasing demand. "For some metals, global mining will have to increase by a factor 20 to 50 by 2050," Kleijn says. "And it can take up to two decades to build a new mine. It means that all major industrial countries are scrambling for these metals, leading to increased geopolitical tension. We will also see a shift in geopolitical power as metal ores not located in the same countries as where coal, oil and gas are located."

Right now, China is a major producer of many of these materials, including cobalt that is mined in Congo but then immediately shipped to China for processing. Kleijn: "It is unbelievable that Europe has invested so little in its refinery capacities. We have become largely to completely dependent on other countries - for oil, coal and gas as well as for the resources we need to realise the energy transition."

RENÉ KLEIJN

POLICY MAKERS

Under the neoliberal paradigm, the dominant perspective of policy makers is one in which the economy is viewed through the lens of globalisation – in which a clear division of labour ensuring production efficiency, specialisation, competition, and international trade have become the main drivers of a self-regulating global market. But it does take government involvement to realise an independence of Russian gas, or to reduce our dependence on heavily polluting energy sources such as coal or oil. "Smart industrial policy could certainly help in replacing the most polluting industrial processes with clean sources such as hydrogen," Kleijn says. "Look at Tata Steel. If the Dutch governmental policy would encourage this company to produce green steel from green hydrogen produced at sea, that same steel could directly be used to build more wind turbines."

GREEN DEAL

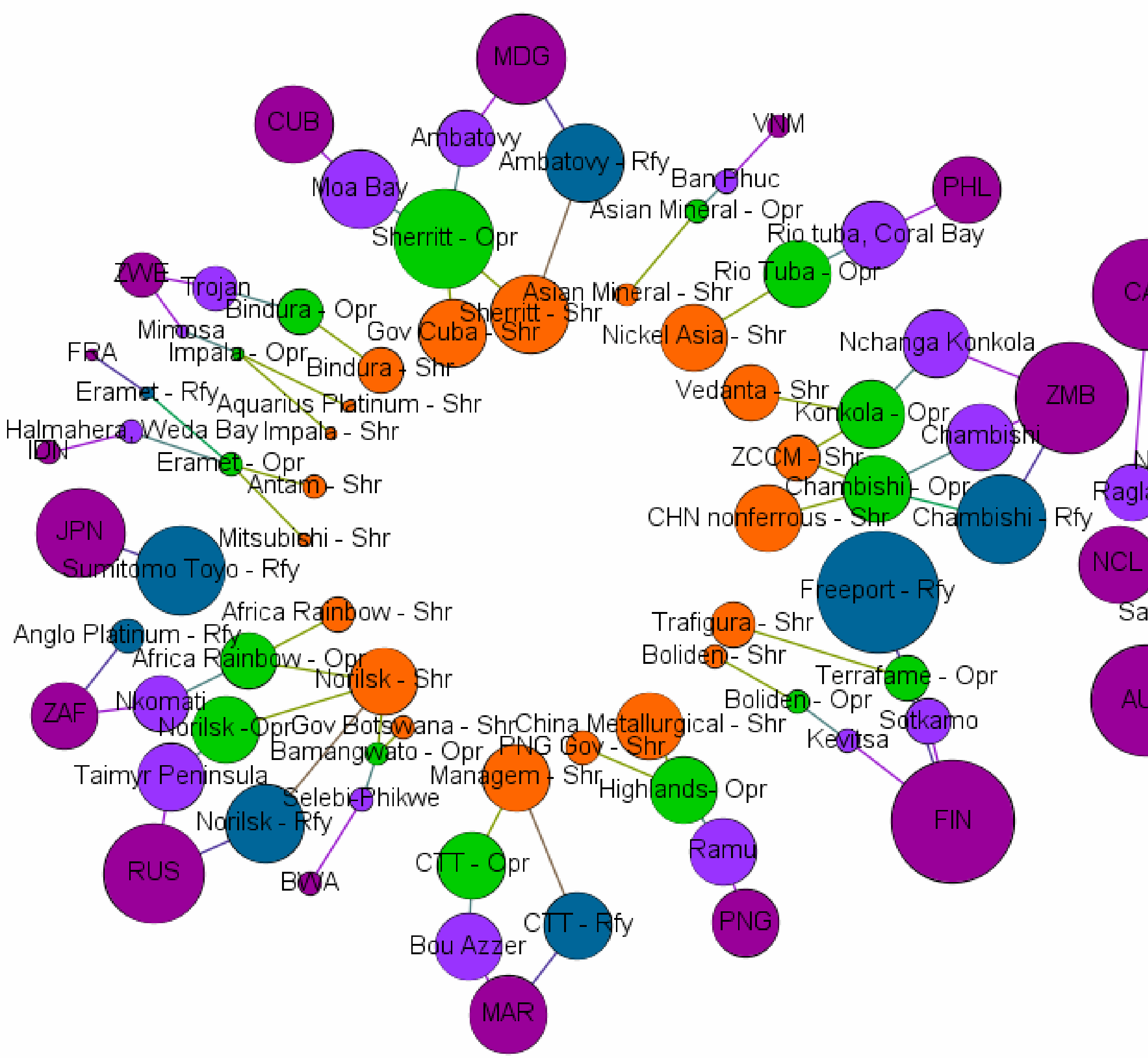
The landmark Green Deal the European Commission presented in December 2019, could be the watershed moment when it comes to the creation and implementation of the industrial policies needed to become energy independent and carbon neutral. Rather than these being top-down policies instituted by Brussels, Kleijn favours to have local communities involved in this transition. "Nobody wants to have a lithium mine in their backyard. We must also make sure that the companies involved in these mining operations pay decent wages and give full compensation to people affected."

It is also important to clearly communicate that the upsides of moving away from a system based on extraction to one based on availability. "We will be much less dependent on inputs once we have erected enough wind turbines, installed enough solar panels, built enough batteries and are able to produce hydrogen on a big scale. After all, wind and solar energy are free resources."

URGENCY

"It takes a sense of urgency to realise this vision," Kleijn says. "The war in Ukraine has demonstrated that global supply chains are vulnerable. And depending on a single country can lead to huge price fluctuations. We must therefore diversify our most important supply chains." Take lithium, for example. It is abundantly available worldwide, but prices are increasing rapidly simply because demand is outpacing production. "Decreasing European dependency on imports means that we will have to build our own mining and refining operations. Reducing our consumption is an important priority as well, of course, but the reality is that our current society needs energy, mobility, and technology. We must really ask ourselves where we want to source the raw materials that we will need in the coming decades."

> ‘WE MUST ALSO MAKE SURE THAT THE COMPANIES INVOLVED IN THESE MINING OPERATIONS **PAY DECENT WAGES** AND **GIVE FULL COMPENSATION TO PEOPLE AFFECTED**’



Cobalt supply chain network 2016: countries (dark purple), mines (light purple) mine operators (green), mine sha
(for countries this includes the mined and refined production). The linkages in orange are connections between
companies and locations. The left image shows 11 small networks of companies, the right image shows a single
Source: Brink, S. van den, Kleijn, R., Sprecher, B. & Tukker, A. Identifying supply risks by mapping the cobalt supp

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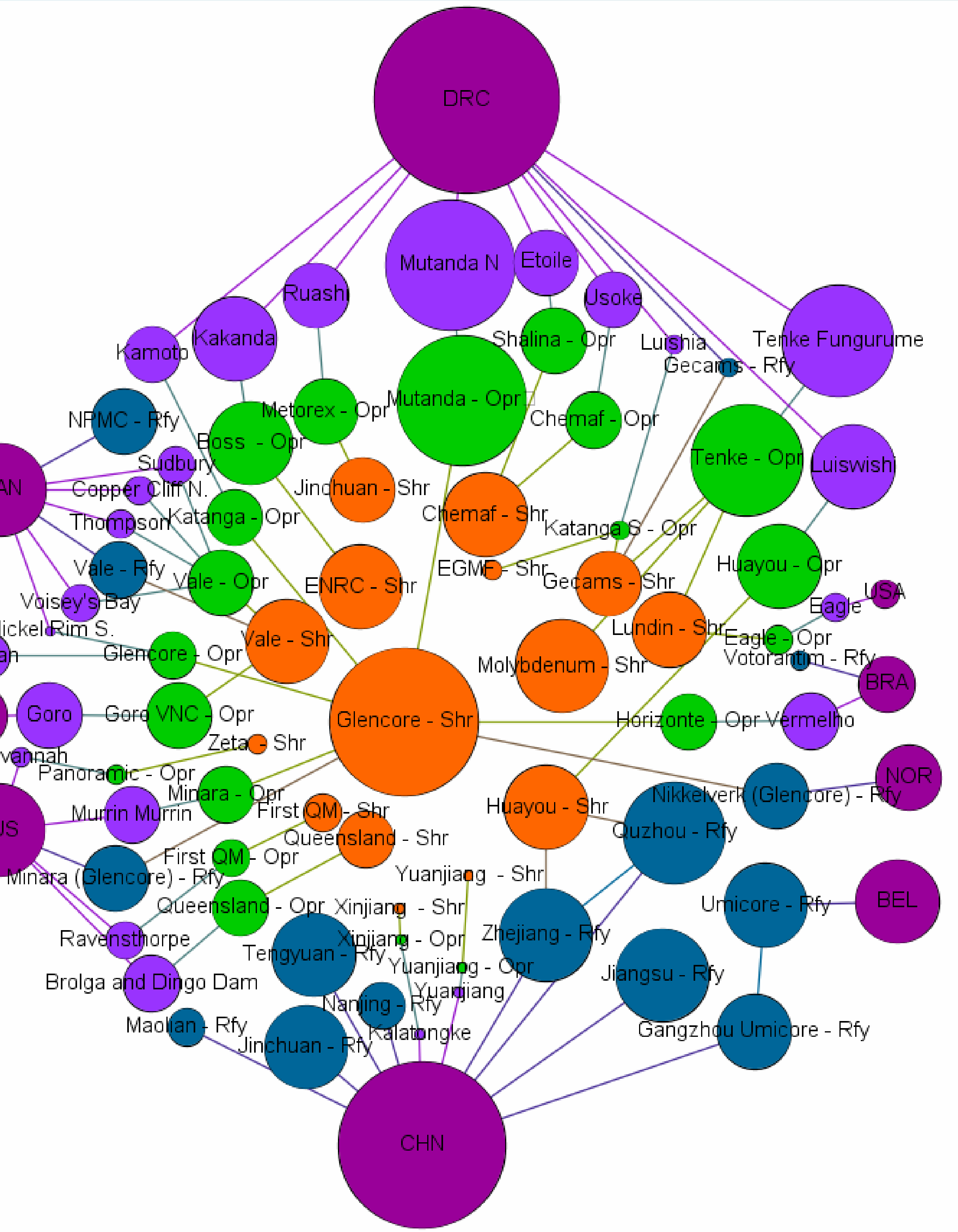


areholders (orange) and refineries (blue). The sizes of the nodes are based on the amount of cobalt produced
companies, in green between operators and mines (the refineries are the operators), and in purple between
network of companies that is used for the analysis.
ply chain. Resour Conservation Recycl 156, 104743 (2020).

Take home messages:

1. The free market falls short when it comes to upscaling critical raw materials.

2. We need EU industrial policy for improving raw material availability as well as environmental and ethical aspects

Photo Getty Images

BENJAMIN SPRECHER

Industrial ecologist and assistant professor at Industrial Design Engineering

TU Delft

“The energy transition has to speed up if we want to meet the goals set for 2050,” says Industrial Ecologist **Dr. Benjamin Sprecher**. “But the recent Russian invasion of Ukraine and its impact on markets has shown that geopolitical aspects play a critical role in the provision of resources in general, and the metals needed to shift toward clean energies in particular.” Especially the price of nickel skyrocketed, and the London Metal Exchange even temporarily halted trade in this metal. “It is still very uncertain how critical materials supply chains will reorient themselves and which resources might next become a problem.”

HUMAN BEHAVIOUR

Sprecher and his team apply dynamic system modelling as means to model the supply chains of various raw materials. These models do not serve to predict the future but rather aim to increase our understanding of how various disruptions, small and large, may affect the system.

Photo Leiden University

The geopolitics of raw materials

Interview with Dr. Benjamin Sprecher

"Unlike weather models these are a direct result of human behaviour," he says. "It is why we continually add new scenarios to the model." In one of his research articles, he describes what could happen to the platinum markets if a civil war would break out in South Africa. "Russia is an important supplier of platinum as well, but I never saw the current war coming. The war makes it very hard to predict what the world, and markets, will look like in five years."

The models result in various option spaces – scenarios that can serve as a basis for drawing up and enforcing policies. They typically cover a long timescale as it takes a lot of effort and time to upscale the extraction of metals. Take lithium, for example, a metal needed in the production of (car) batteries.

"There is a worldwide abundance of lithium, and it could even be extracted from water, but it takes years before a new mine is up and running," Sprecher says. "Besides regulatory approvals, you also need to get the local people on board. It also takes up to 18 months to adapt a battery factory to a new source of lithium as the composition depends on how and where it was extracted."

INDUSTRIAL POLICY

To Sprecher, a shortage in the abundantly available lithium proves that the free market falls short. "Net production simply is too low," he says. "Commercial parties refrain from entering long-term commitments as they rather await the outcome of elections and the introduction of new policies. In the worst of cases, materials are not available at all, while in the best of cases you may just have to deal with extremely high prices every once in a while."

Some form of industrial policy seems necessary to counter market shortages or even chaos. "China has become a dominant power in many critical materials because the government proactively boosted certain sectors, providing financial support," Sprecher says. "We need such industrial policy in Europe as well. Not only from a financial perspective. Leaving it to the free market has proven to be a bad idea."

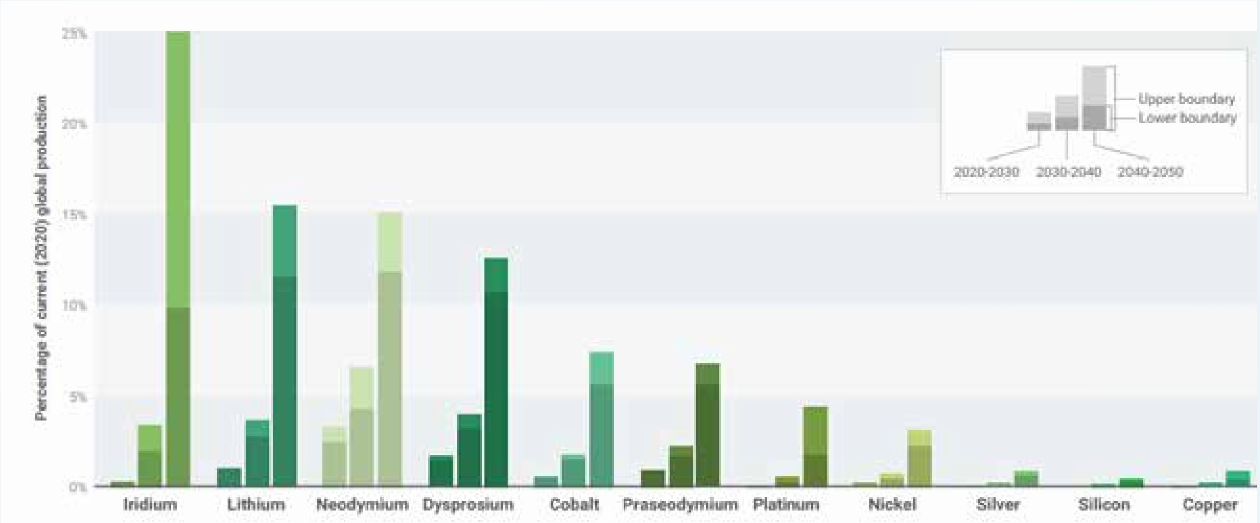
CIRCULAR THINKING

Besides ensuring critical materials supply through industrial policy, circular thinking can also help reduce shortages of critical metals. This can be achieved by increasing the lifespan and recyclability of products. France set the example by passing a law stating that, by 2024, products must meet certain reparability standards before they can be sold. Sprecher: "I think this is a great idea. The longer the lifespan of products, the fewer raw materials you need for the same functionality. And when it comes to recyclability, it would be much easier to recycle solar panels if they were no longer glued together."

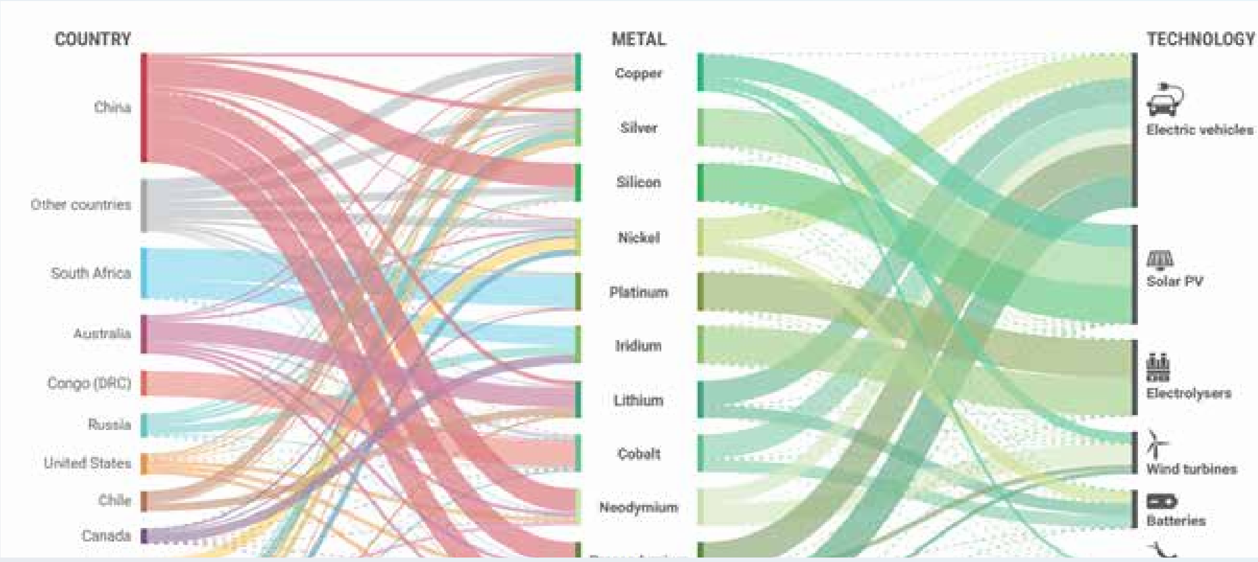
Sprecher hopes the war in Ukraine serves as a wake-up call. "The world is already late in acting. We have to start now in making every effort imaginable."

'CHINA HAS BECOME A DOMINANT POWER IN MANY CRITICAL MATERIALS BEACUSE THE GOVERNEMENT PROACTIVELY BOOSTED CERTAIN SECTORS'

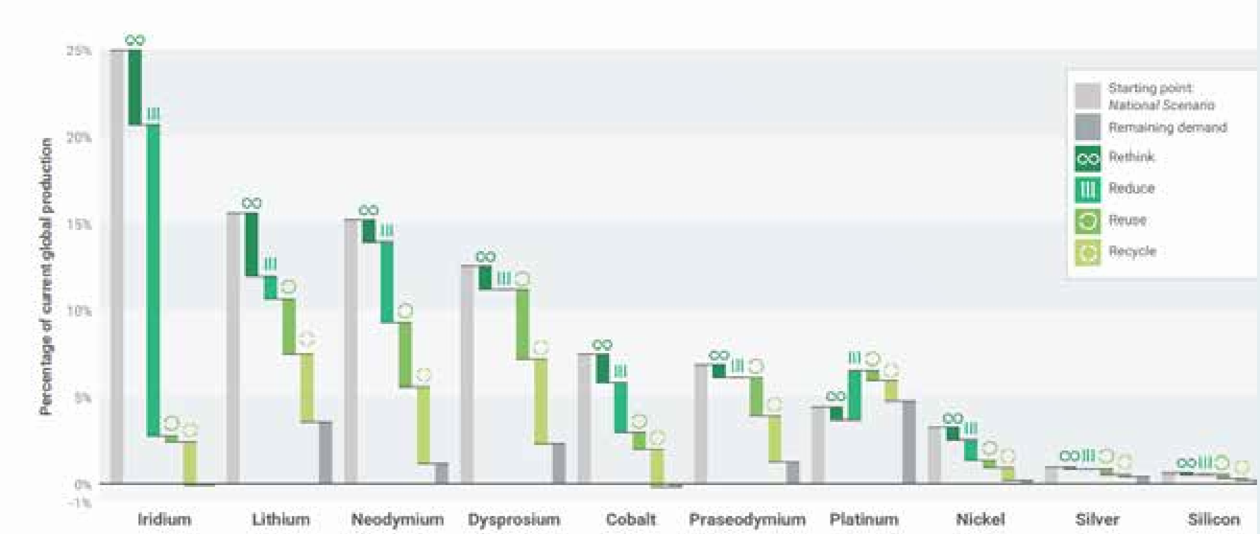
Photo Getty Images



Expected annual demand for a number of critical metals as a percentage of current global production, for the periods 2020 to 2030, 2030 to 2040, and 2040 to 2050.
Source: https://www.metabolic.nl/publications/towards-a-circular-energy-transition/, figure 13, page 21



Extraction of critical metals needed for a sustainable energy system.
Source: https://www.metabolic.nl/publications/towards-a-circular-energy-transition/, figure 14, page 23



Potential effect of the combination of the four circular strategies on the annual metal demand (period: 2040 to 2050) for the ten metals with the highest relative demand.
Source: https://www.metabolic.nl/publications/towards-a-circular-energy-transition/, figure 17, page 27

Take home messages:

1. Many criteria for a circular economy were met during World War II.

2. Some government policies are needed to increase the speed of the energy transition.

Photo Getty Images

DAVID PECK

Associate professor in the Faculty of Architecture and the Built Environment. He is specialized in critical materials and circular product design.

Photo David Peck

TU Delft

As consumers, we mainly notice the shortages in sunflower seeds and grain, caused by the war in Ukraine, and the shortages in computer chips that is a result of the COVID pandemic. But there are more shortages, especially impacting the resources needed to accomplish the energy transition. In his PhD-thesis, **dr. David Peck** analysed various response strategies to resource constraints. "We can learn a lot from how governments have tried to resolve these issues in the past."

SHORTAGES OF ALL AGES

During World War II, world markets and the supply chains of many materials were adversely impacted on an unprecedented scale and many countries struggled with rampant shortages. Between 1940 and 1944, targeting of transport vessels resulted in commodity shipments to the United Kingdom dropping by 50% while demand remained high. "The technology and the geopolitical situation were completely different back then, as were the kind of materials that were in short supply," Peck says.

Material shortages and industrial policies: from past to present

Interview with Dr. David Peck

“You could argue that this makes an invalid comparison. But we must realise that specific materials can literally define an era, think of the Stone Age and the Bronze Age. Nowadays, it is lithium and cobalt.”

The past can also serve as an example when considering the urgency of the present challenges. Peck: “Europe wants to reduce its raw material use and carbon emissions by 50 percent in seven years from now. Back then, the United Kingdom achieved this in only two years, so there are lessons to be learned.”

LICENSE TO OPERATE

During his PhD, Peck did not look at the production of weapons. He rather studied ordinary products such as clothing, pottery, and furniture. “During war, laborers still need a bed to sleep, a table to eat at, and a plate to eat from. Therefore, these were essential products to be produced during war time.” One of his primary interests involved the policies set by the British government through which they intervened in any and all production. “A license to operate became obligatory and private companies worked under government contracts. The government decided what would be designed and produced, to make sure the economy would continue to function.”

The British government took complete control, altogether changing the structure of supply and demand. They appointed six senior policymakers, with another six industrialists being responsible for certain industrial sectors. Peck: “These twelve men basically sat down and said: this is what we have, this is what we want to make, and these are steps we need to take to make it work. Production of non-essential products was put to a halt.”

UNINTENTIONALLY CIRCULAR

In a normal market, production would cater to what is likely to sell. In Britain during

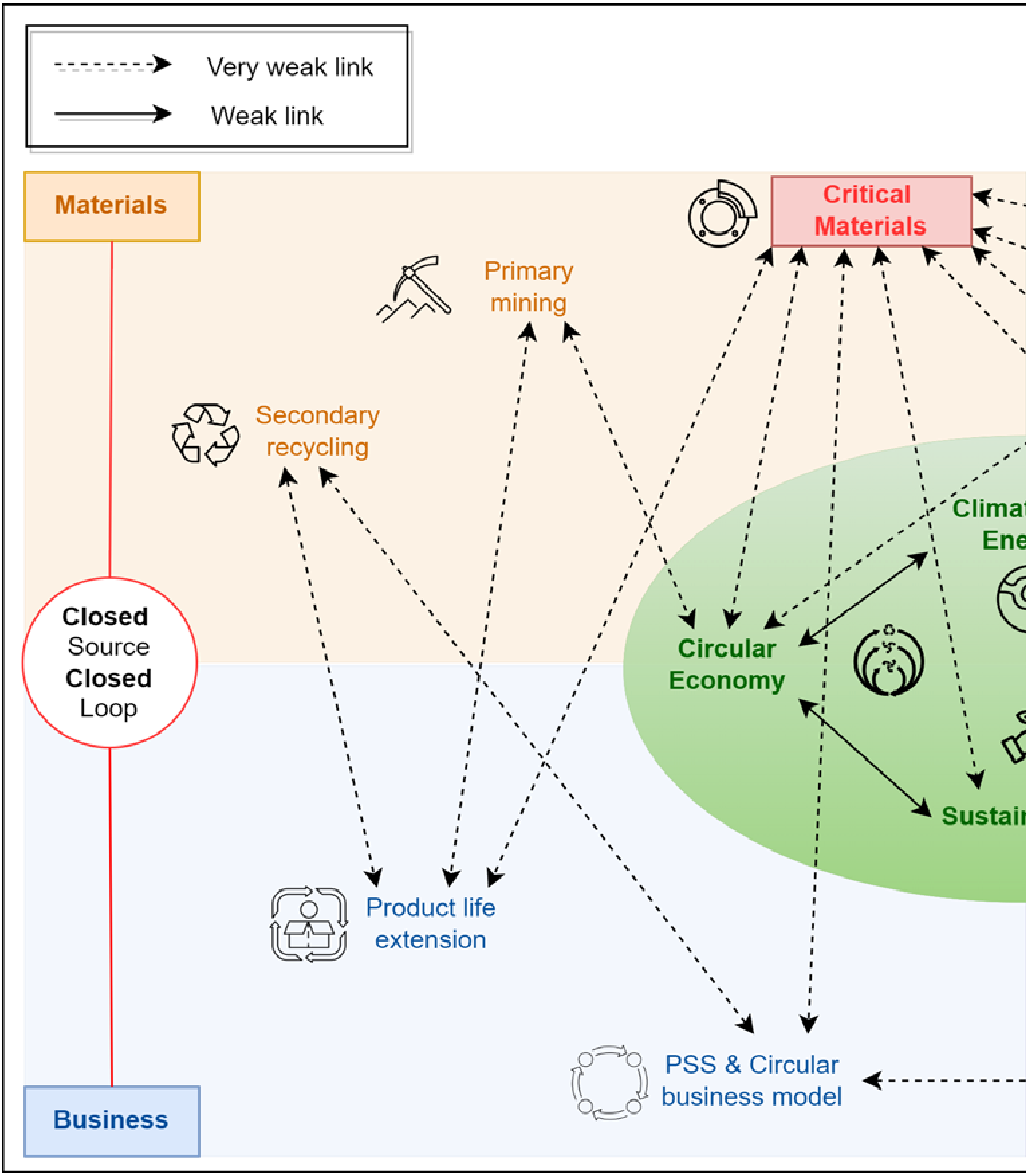
World War II, however, it was up to a panel of designers to come up with the most efficient products designs, such as minimalistic furniture. "It had to be cheap, require little and preferably locally sourced material, and had to be easy to manufacture," Peck says. "Nobody knew when the war would end, so they were built to last. Some chairs are still collectors" items as they were so well made." The government also issued 'make do and mend' pamphlets, providing housewives with useful tips on how to be both frugal and stylish in times of harsh rationing. "Unintentionally, they were quite environmentally conscious. I find it very interesting that many of the criteria for a circular economy were met during the war."

YET ANOTHER STORAGE

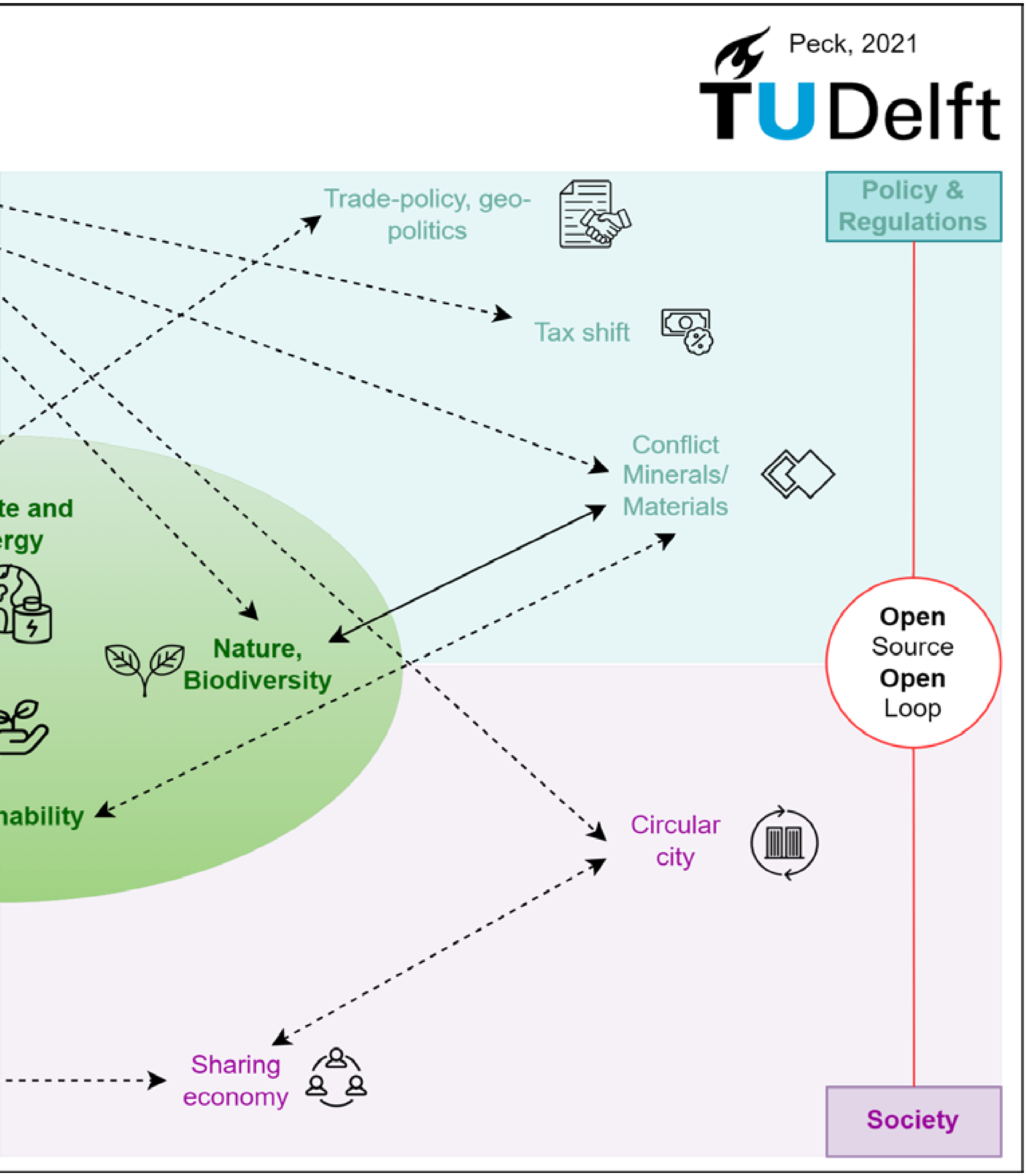
To Peck, there are parallels with the war in Ukraine as this conflict also forces us to rethink our global supply chains. "A major difference is that the current transition is led by the private sector with the encouragement of governments, while during World War II it was led by the state with the involvement of the private sector," he says. He understands the reluctance of politicians to intervene, as they would face resistance from both the private sector and citizens. "The policy measures can perhaps be somewhat less draconian, but we do have to act fast and decisively, just like back then. So, we need some form of centralized control."

Interest in critical materials on a policy level is higher than ever before, and Peck has been repeatedly interviewed by the Dutch media. "We are moving in the right direction, but not fast enough. The supply chains of critical materials are extremely dynamic and complicated. There are thousands of questions that need answering but, with all scholars specialised in this topic fitting into a single meeting room, we lack sufficient research capacity."

'A MAJOR DIFFERENCE IS THAT THE CURRENT **ENERGY TRANSITION** IS LED BY THE PRIVATE SECTOR WITH THE **ENCOURAGEMENT OF GOVERNMENTS**, WHILE DURING WORLD WAR II IT WAS **LED BY THE STATE** WITH THE INVOLVEMENT OF THE PRIVATE SECTOR.'



Weak and very weak linkages between key dimensions of critical materials and circular economy.
Source: None. Original figure by David Peck, edited by Elise Blondel



Peck, 2021
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Policy & Regulations
Trade-policy, geo-politics
Tax shift
Conflict Minerals/ Materials
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Open Source Open Loop
Circular city
Sharing economy
Society

Take home messages:

1. The EU can no longer rely on market mechanisms to solve all its raw materials problems

2. Strategic access to rare earth metals is also about the willingness to invest domestically.

Photo Pexels

JEWELLORD (JOJO) NEM SINGH

Assistant professor at the International Institute of Social Studies

Photo ISS

International Institute of Social Studies, Erasmus University Rotterdam

Rare metals are important in building the technology the EU needs to realize energy independence, and to achieve the political goals set out in the Green Deal by the European Commission. It is a market that is currently dominated by China. "There is growing awareness among western countries that they should not be totally dependent on China anymore," **dr. Jojo Nem Singh** says. "The fundamental issue is that production and processing of rare earth elements is done almost exclusively in China."

THE COST OF AUTONOMY

Born in the Philippines, Nem Singh has a pragmatic view on the rise of China – almost uncluttered by the global power struggles often shaping political debates in European capitals. The premise of his most recent paper ("Mining our way out of the climate change conundrum") is that the costs of mineral extraction need to be shared more equally.

The (local) cost of reducing our dependency on imported raw materials

Interview with Dr. Jojo Nem Singh

Nem Singh: "To achieve its desired strategic autonomy, the EU has to face the reality that our production and consumption have been accommodated by China for many years."

Strategic autonomy also means becoming more independent from the United States, Russia, and South Africa. "We have gotten used to paying low prices for commodities, electronics, and consumer goods. If Europe wants to develop regional supply chains, we need to consider their actual value. Europe needs to start thinking about its own role in the extraction processes needed for the green transition."

SACRIFICE

"Politics of sacrifice" is an appropriate concept that Nem Singh draws from the works of human geographers, signifying the ethical question behind the policy. "Mining rare metals can be fraught with high environmental, social and health costs," he says. "There is always someone, somewhere, who sacrifices something and, right now, this is not openly discussed in the EU. By refusing to build the much-needed new mines for the green transition ourselves, Europe simply pushes these harmful side-effects down the line to developing countries."

Whereas communities at the mining frontier often suffer the most damage, these areas also tend to benefit from mineral development as a result of economic gains from extraction. "Rather than continuously believing that market mechanisms will solve problems like market failures and redistribution of environmental goods and bads, the EU must pass stricter legislation regarding environmental issues and labour issues. It must also recognize that when new mining projects are rejected in Europe, important metals like cobalt, rare earths and lithium need to be outsourced elsewhere under dramatically weaker social, legal and environmental frameworks."

FUNDAMENTAL OBSTACLE

Nem Singh identifies several disconnects between the public perception and the reality of mining: the expectation of consumer products to be produced cheaper while demanding high ethical standards in the production processes, the delayed reaction of the EU regarding resource dependence, the highly ambitious political goals set out in the Green Deal, and the political realities of how member states make decisions regarding mining projects across the continent. "The complexity of the EU decision-making process has been a fundamental obstacle to the green transition," he says. "Take trade policies, for example. The EU Commission has direct policy competence and can craft policies applicable to all member states, but mining policy is a national competency and therefore subject to domestic political discussions."

Fieldwork performed by Nem Singh and his colleagues shows that EU goals often clash with domestic environmental and social policies. "To realize an EU strategy of setting up domestic or regional supply chains for the resources it needs, member states should be lining up right now to start developing mining industries," he says. "Instead, it is really hard for national governments to open up new mines."

LUXURY POSITION

With the climate crisis a reality, EU industrial competitiveness depends on securing all kinds of rare metals in markets fully dominated by China. "The EU still thinks it is in the luxury position of procuring all primary materials in a world market that sets market prices for commodities efficiently and fairly all the time," Nem Singh says. "But with politics and economy becoming ever more intertwined, that is no longer true. Countries such as China, Brazil, and South Africa know full well that western countries are in dire need of rare earth metals. China has used its monopoly position to control prices, support its own companies and outcompete its counterparts abroad. And, of course, the Chinese government learned how to develop their own technology in processing, giving them a competitive advantage in the medium-term."

A NEW PERSPECTIVE

The ambitious goals set out in the Green Deal could change things for the better, as it fuels the political will to debate what is needed. Nem Singh: "Strategic access to rare earth metals is not only a matter of global trade. Importantly for the EU, a key issue is the willingness to invest in a regional supply chain." This will require a shift in political attitude as mining intrinsically is a high capital, high cost, undertaking – looking at ten years of losing money, under the constant uncertainty of a price collapse as commodity markets are very volatile. "That is what EU decision makers will need to explain to citizens. Access to resources, being of such strategic importance, can no longer be looked at from a market perspective."

'STRATEGIC ACCES TO RARE EARTH METALS IS NOT ONLY A MATTER OF GLOBAL TRADE.'

Photo Getty Images


CHOICE
DON'T NUKE THE CLIMATE
YOUTH CHOOSE
CLIMATE JUSTICE!
COLUMBIA
FOR CLIMATE

Take home messages:

1. A good deal of the material resources needed for the energy transition can be found in what is now called the urban mine.

2. As a society, we must organize these processes on an industrial scale, and we need to start planning for that right now.

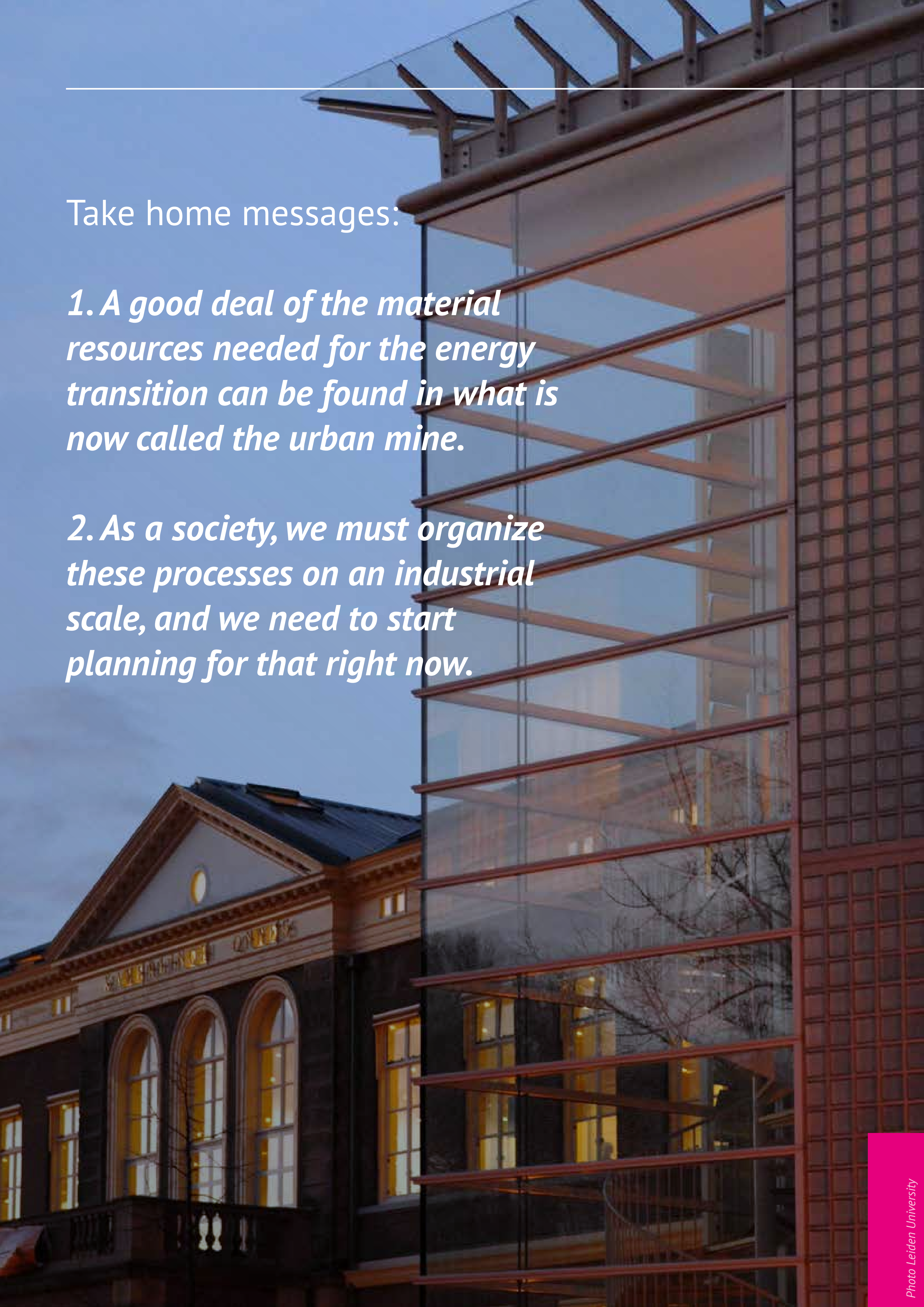


Photo Leiden University

ESTER VAN DER VOET

Professor Sustainable Resource Use at the Institute of Environmental Sciences

Universiteit Leiden

Photo Leiden University

The Institute of Environmental Sciences (CML) of Leiden University

Urban mining is a relatively new concept. It perceives the whole of society as a mine containing large quantities of resources. “Take the company Umicore, for example,” **prof. Ester van der Voet** says. “As a former mining company, it had a bad reputation when they were mining in Congo. They now operate from the Port of Antwerp, where they recycle mobile phones, laptops, and industrial waste into useful materials. In a real circular economy, you would fundamentally want to avoid opening new mines, as most of the materials you need are already in use somewhere in society.”

Urban mining: raw materials in your back yard and pocket

Interview with Professor Ester van der Voet

OFFICIAL INVENTORY

Van der Voet and her team of researchers have calculated the resources that could be extracted from large scale energy networks, such as electricity cables or the gas grid. And they are preparing an official inventory of the size of the urban mine in the Netherlands, for the Dutch Environmental Assessment Agency (Planbureau voor de Leefomgeving). "Materials will become available from consumer products such as cars, electronics, and the furniture that we use in our daily lives. For each of these, we can calculate the amount of useful and recyclable materials they contain. We can reuse these, rather than opening yet another coltan mine."

"The energy system of a country contains enormous amounts of steel, copper, or aluminium that can be reused after the cables and pipes are replaced," van der Voet says. "That way, you won't have to constantly mine new materials. You will also save a lot of energy as mining constitutes using large machines to extract massive amounts of rocks for what is, in comparison, only a tiny fraction of metal. Then comes the processing, which is also very energy intensive. To turn bauxite into aluminium, for example, you'll have to break the strong chemical bonds between aluminium and oxygen. Why would you want to do all that if you can just reuse the aluminium already available?"

A MATTER OF TIME

A dilemma of urban mining is that most of the materials that could be turned into useful resources are still in use right now. That makes the concept hard to sell. "Urban mining involves investing money into resources that will only become available decades from now," Van der Voet explains. "The underlying products do, however, have certain life spans and you can plan for that." She has already developed several scenarios to assess the amount of material that will become available by 2050.

Van der Voet: "Especially during an era of transition, such as the energy transition, many systems will be replaced: refineries, gas production installations, oil tankers, gas pipelines, you name it."

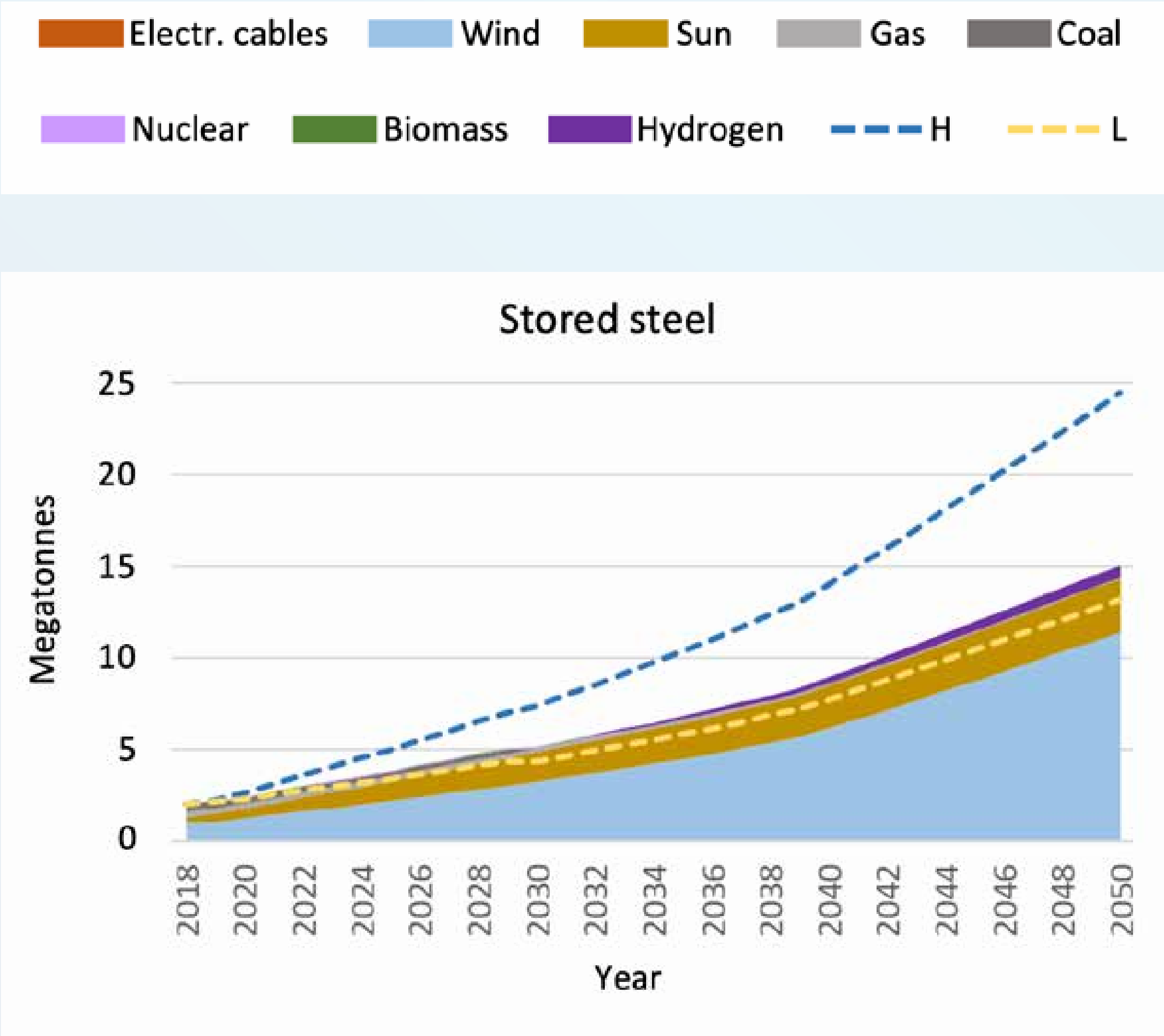
'URBAN MINING INVOLVES INVESTING MONEY INTO RESOURCES THAT WILL ONLY BECOME AVAILABLE DECADES FROM NOW.

THE UNDERLYING PRODUCTS DO, HOWEVER, HAVE CERTAIN LIFE SPANS AND YOU CAN PLAN FOR THAT.'

INCREASING RECYCLABILITY

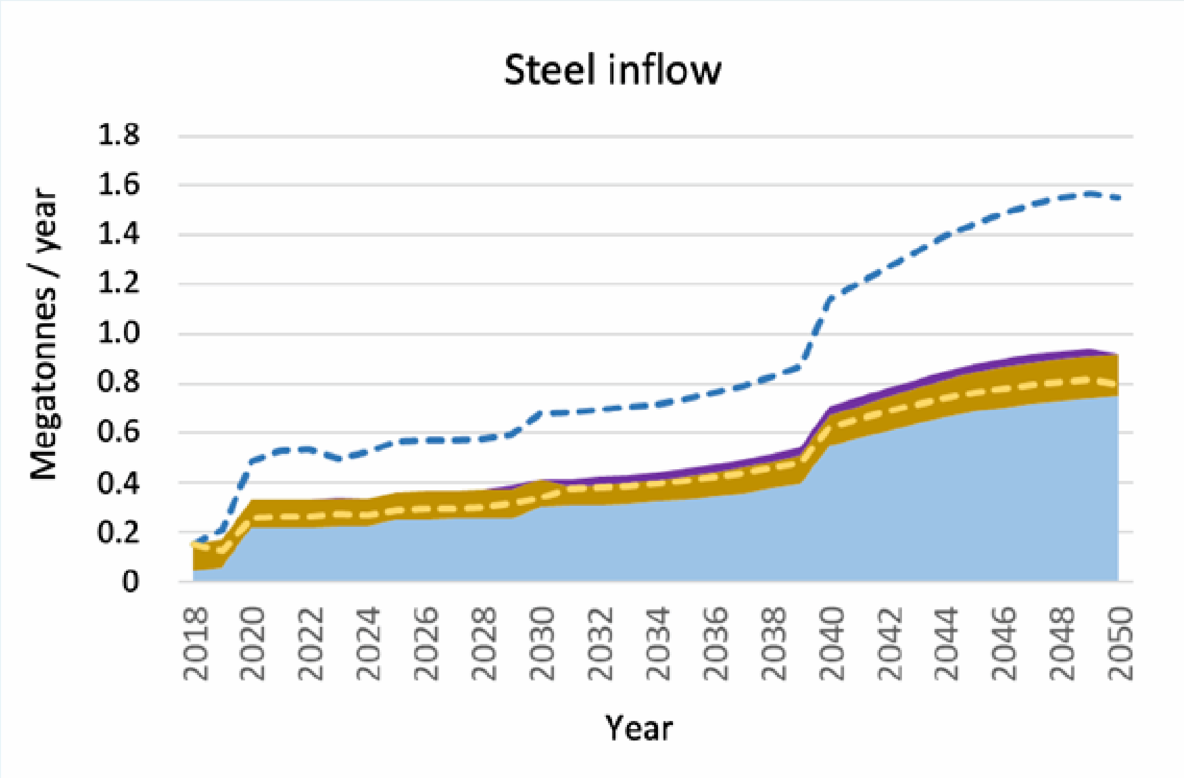
Fair to say that the urban mine is a huge resource, but more research is needed to make these a reality. "We will have to carefully consider how and at what scale we want to organize extraction from the urban mine, and how we will go about processing those materials," Van der Voet says. "It is not feasible, nor desirable, to build a copper smelter in every town. It would therefore be incredibly naïve to rely on local self-sufficiency. As a society, we must organize these processes on an industrial scale, and we need to start planning for that right now."

It would also be smart to improve the design of products, making them easier to disassemble and recycle. "It is about how materials are combined, down to the chemical level," Van der Voet says. "Steel is often made with alloying elements, to make it more heat resistant for example. If you manage to develop steel with the same heat resisting attributes while considering the diverging melting temperatures of the metals needed, you can already take into account the energy needed to separate them again during recycling. This could increase the quality as well as the applicability of recycled steel."



A medium scenario for stored steel, steel demand (inflow) and discarded steel (outflow) of the electricity system in the Netherlands until 2050.

Source: https://www.universiteitleiden.nl/binaries/content/assets/science/cml/publicaties_pdf/rapporten/scenarios_elektriciteitssysteem_final.pdf, page 20.


Steel inflow
Megatonnes / year
1.8
1.6
1.4
1.2
1.0
0.8
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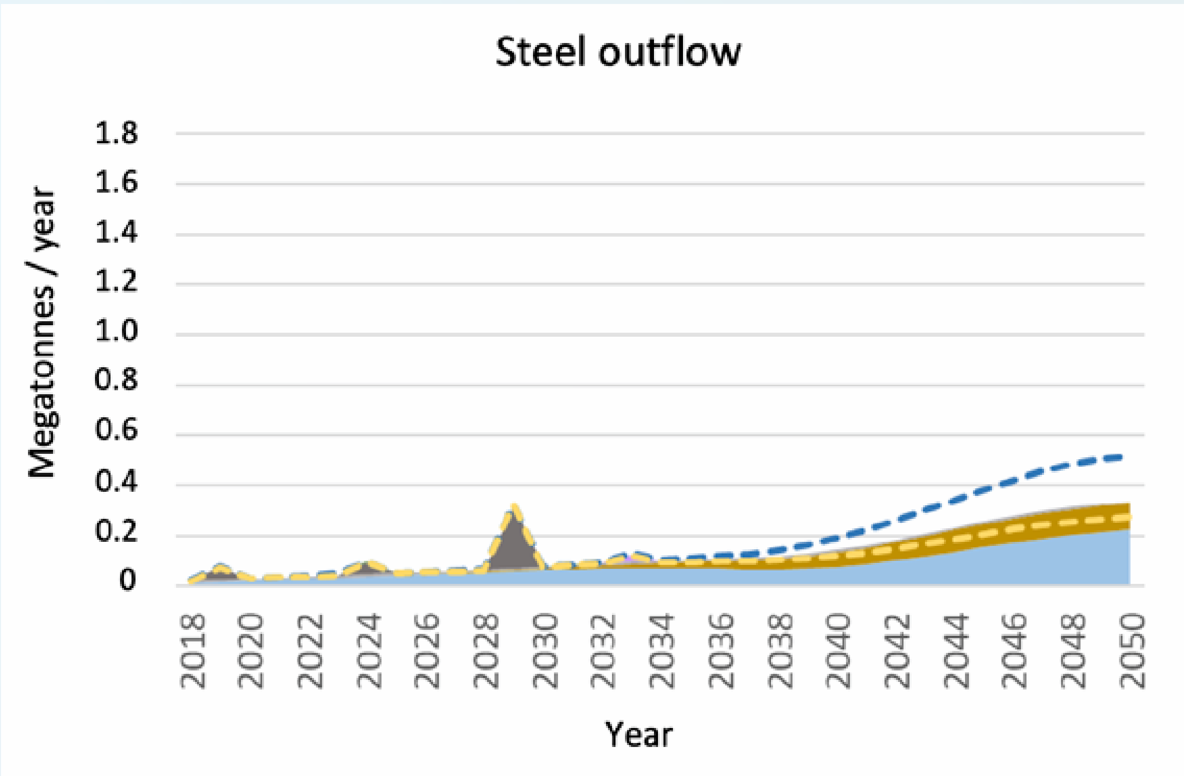
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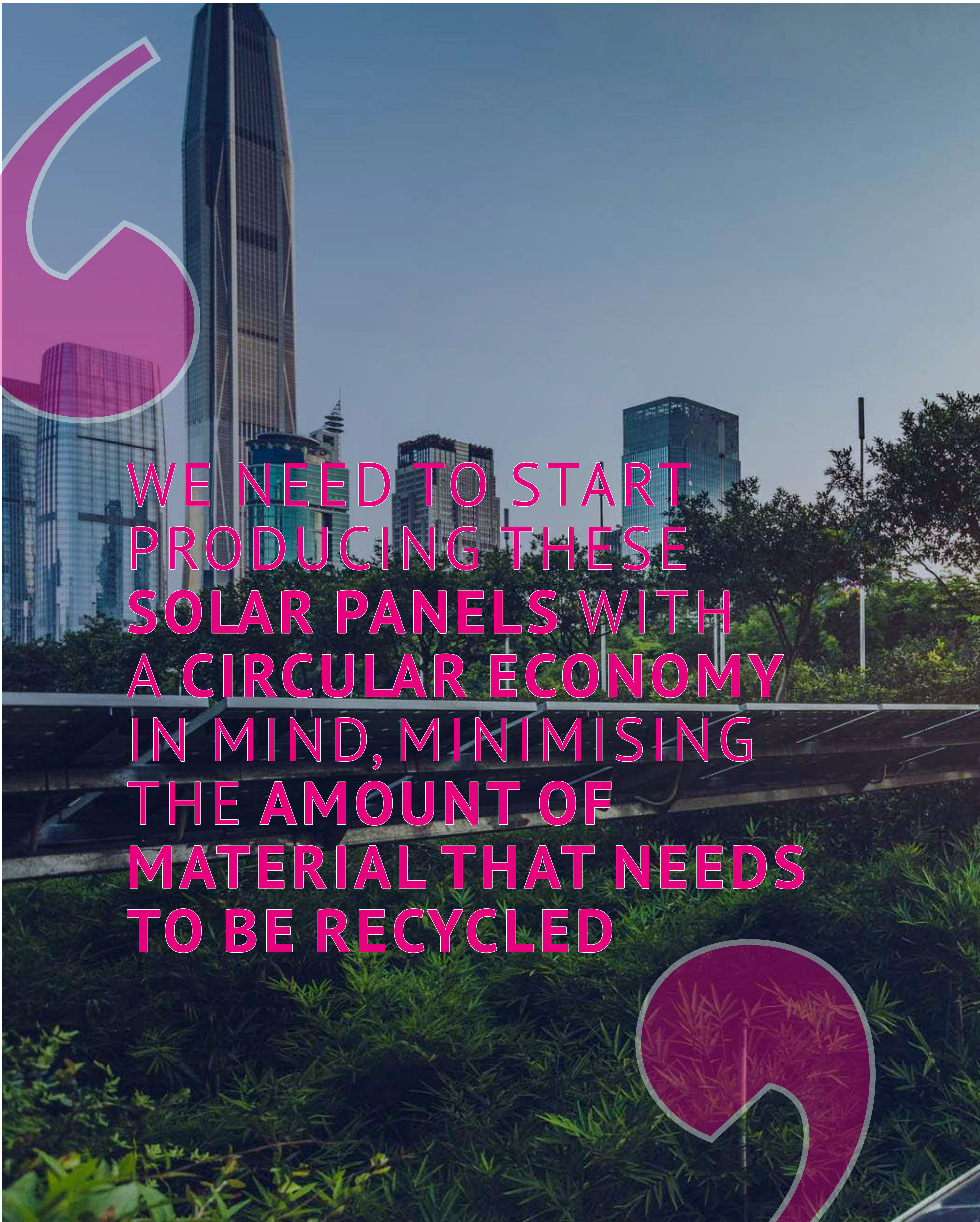


WE NEED TO START PRODUCING THESE **SOLAR PANELS** WITH A **CIRCULAR ECONOMY** IN MIND, MINIMISING THE **AMOUNT OF MATERIAL THAT NEEDS TO BE RECYCLED**


Photo Getty Images

Take home messages:

1. The vast majority of installed solar panels will not be up for recycling for at least the next two decades.

2. We need to start producing these panels with a circular economy in mind, minimising the amount of material that needs to be recycled.

Photo TU Delft

OLINDO ISABELLA

Full professor in Photovoltaic Technologies and Applications.

Photo TU Delft

Faculty of Electric Engineering, Mathematics and Computer Sciences, TU Delft

Professor Olindo Isabella considers it his mission to have pholtovoltaic installations on every surface possible.

Last year, the Netherlands capacity for creating solar energy increased with 30% to a total of 11.4 billion kWh – equalling 67 square kilometres of installed solar panels (solar photovoltaics, PV). Worldwide, more than 6000 square kilometres of solar panels have been installed.

That is a lot of material that could, and should, be recycled at the end of its lifetime. But it is not immediately available. “Solar panels have a technical lifetime of 25 to 30 years,” Isabella says. “The vast majority of panels, more than 85%, has been installed in the past five years. Right now, there are only very few, very old panels that have reached their end-of-life.”

Recycling solar panels: a solution waiting to happen

Interview with Professor Isabella

CRITICAL AND NOT SO CRITICAL MATERIALS

When it comes to the materials used in PV, it makes sense to differentiate between the solar cells (the opto-electrical devices that convert solar rays into electricity) and the module (the object you lay on the rooftop). A module is an assemblage of solar cells sealed in a protective laminate. An aluminium frame clamps around its perimeter with glass sheets at the front and back for mechanical rigidity and to protect the solar cells from all sorts of weather conditions. "Current generation solar cells mostly consist of silicon – the semiconductor material converting solar energy into electricity – coated by aluminium-based contacts," Isabella says. "Some silver is used to create solderable grid patterns at the front and backside to collect the photocurrent."

There are two contenders to become the dominant architecture of solar cells in two to three years, one of which (called heterojunction) uses transparent layers consisting of indium-oxide doped with tungsten or tin. "Of all these materials, silver and indium are the critical raw materials for the PV industry," Isabella says. "If the current growth rate increases, going into terawatt scale production, we'll end up using more than 50% of global silver mining capacity by 2050. And for indium, we'll be competing with flat panel display technology, which enables televisions, laptops, mobile phones."

RECYCLING PV

To understand the recycling process, it helps to understand that solar panels are a sandwich construction of glass, plastic, then the solar cells, plastic again, and an encapsulant or glass for protection from moisture. All layers are put in a laminator, melting the plastic, thereby sealing everything. Isabella: "It is very difficult to remove this plastic from the rest. The current recycling technique starts with crushing the panels into millimetre size pieces. These are put in a high temperature furnace to burn off the plastic. At this temperature, the metals – especially the silver and aluminium – may start to alloy with the silicon, making it nearly impossible to separate these. In case of heterojunction solar cells, the presence of indium oxide makes the recovery of different materials even more problematic."

So, whereas aluminium frame of the module can be easily recycled, and the glass can be recovered, the critical raw materials of the solar cells – silver and indium – cannot. And it would take several more chemical and thermal steps to purify the silicon to the point where it can be reused. Given the complexity and cost of the recycling process as well as the price volatility of raw materials, it is understandable that there are only a few companies worldwide that do recycle solar panels into reusable raw materials. "Recycling PV is really at its infancy," Isabella says. "Right now, our best defence to potential material shortages may be to lower the use of these materials in PV. There is a lot of ongoing research, worldwide, into achieving this."

REDUCING CRITICAL MATERIAL DEPENDENCY

A first research direction into lowering this dependency is to go from mono-facial solar cells to having the backside of a solar panel collect light as well. Isabella: "This may increase overall yield by 30%, depending on the installation properties. It also means that the full-area layer of aluminium at the rear of the solar cell is replaced by a grid pattern, thereby substantially reducing material use." A second research direction is to replace aluminium and silver with copper-based contacts. "There is an abundance of copper, and it is available almost everywhere. This limits the possibility of geopolitical frictions."

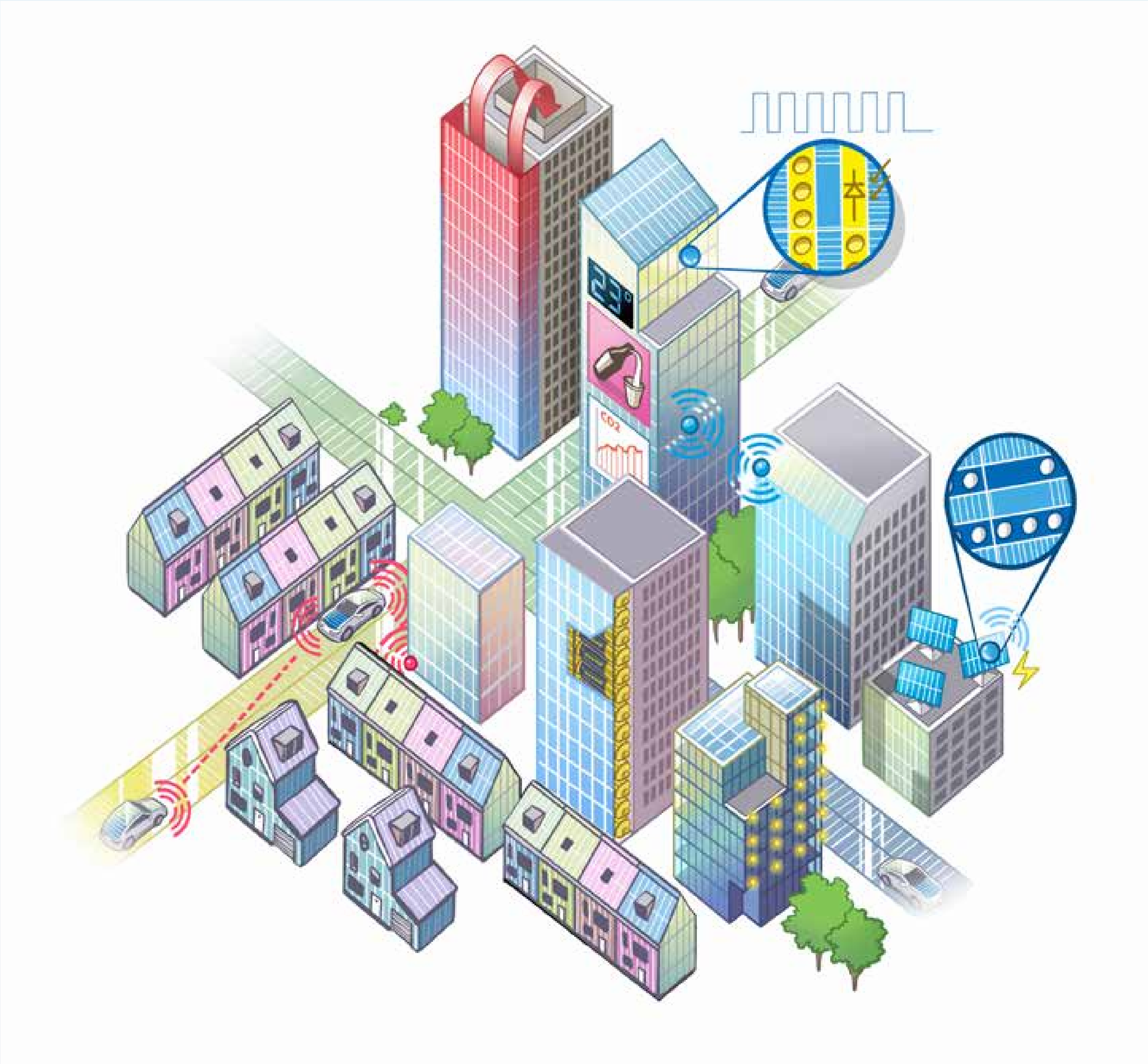
As far as the up-and-coming solar panels using indium are concerned, there is ongoing research into reducing the thickness of the indium-containing layer, into reducing the indium content to only a fraction of what is currently being used, and into shifting to alloys that are indium-free. "It will take a while for these developments to make it from the research phase into commercial solar panels. But reducing the thickness of the indium-containing layer is something that could be applied immediately at industrial level." Both approaches towards reducing material usage are being investigated in the clean room of the TU Delft PV Technology Centre.

It also helps to extend the lifetime of solar panels by making them smart. "We call this photovoltatronics," Isabella says. "By adding a small, printed circuit board we can balance the power-output from shaded and non-shaded parts of the solar panels. It increases both the yield and the lifetime of the panel, especially for PV that is installed in an urban setting."

PV WITHOUT PLASTIC

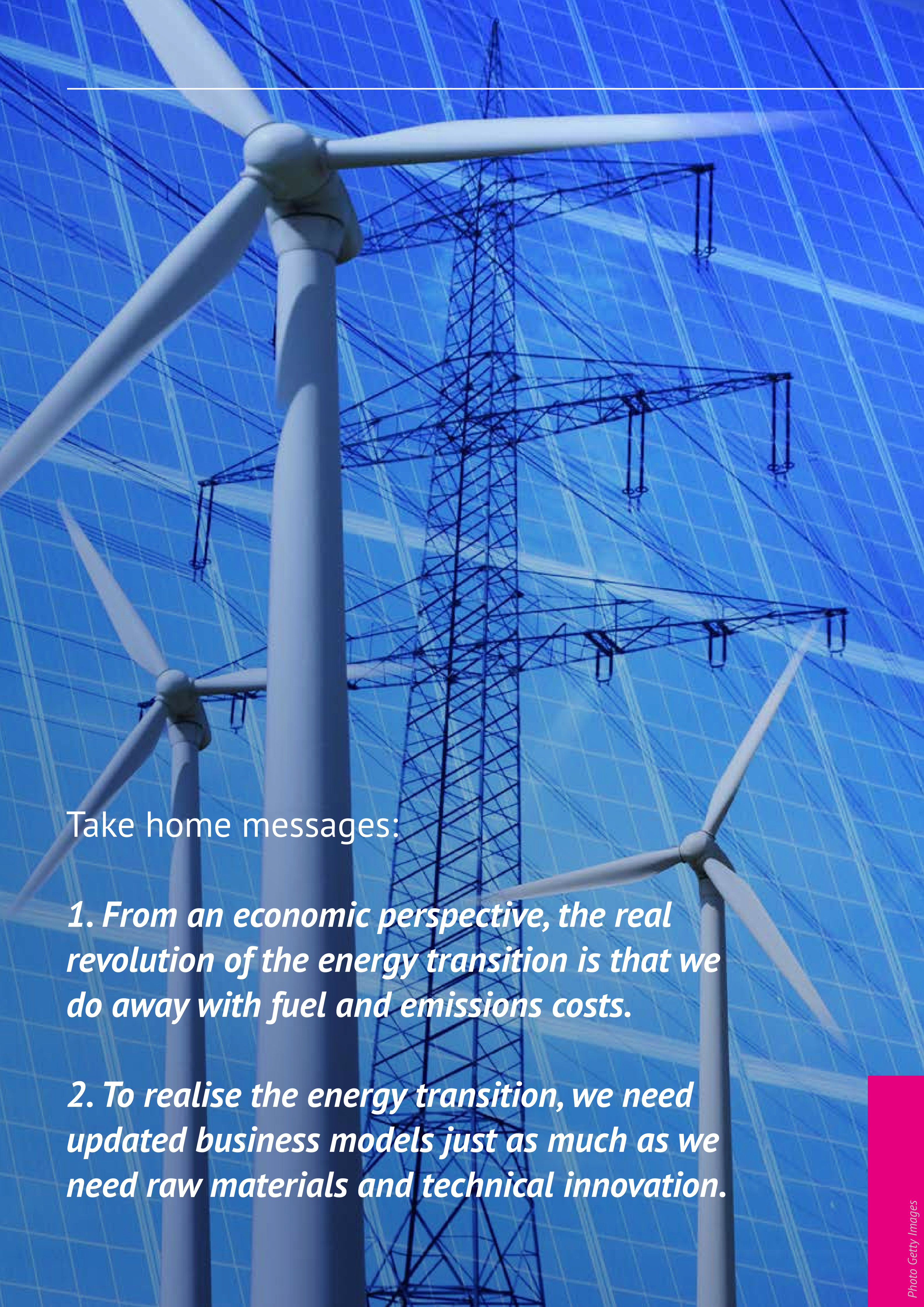
No matter how little critical raw material is used, solar panels will eventually reach their end of life. Therefore, circularity is a topic that deserves attention no matter what. "This is something we are now starting to study and evaluate, in the community as a whole and in my group," Isabella says. "Increasing the recyclability by completely removing the plastic from the solar panels is only one step. We need to start producing these panels with a circular economy in mind, minimising the amount of material that needs to be recycled."

It will take some years to reach this point as these ideas need to be tested in the lab and in the outdoor in terms of reliability. Isabella: "It would also mean a complete change in the way industry makes solar panels."



The usage of available renewable energy sources will be critical in the electricity-driven energy system of the future. Circular photovoltaic systems can pave every surface in the environment providing useful green electricity for the sustainable electrification of society. Shade-resilient, high-performance modules integrated with storage of energy and communication capabilities will constitute PV-based intelligent energy agents. These will cover the whole conversion chain from photons to electrons to bits, marking the advent of the age of photovoltatronics.

Source: https://www.tudelft.nl/2020/ewi/photovoltatronics-slimme-zonnecellen-die-met-elkaar-praten



Take home messages:

1. From an economic perspective, the real revolution of the energy transition is that we do away with fuel and emissions costs.

2. To realise the energy transition, we need updated business models just as much as we need raw materials and technical innovation.

Photo Getty Images

RONALD HUISMAN

Associate professor at the Erasmus School of Economics, specialised in how energy markets function.

Photo Erasmus University Rotterdam

Erasmus University Rotterdam

Without access to raw materials, it is impossible to build the wind turbines and solar panels that are at the heart of the energy transition. Continuous innovation is needed to make these sources of energy cheaper to produce, increasingly efficient, more sustainable themselves, and to smoothly integrate them into our energy grid. And then there is the financial aspect, which plays an important role in the energy transition as well. It is a specialty of **Dr. Ronald Huisman.** "If the European Union wants to reach its emission reduction targets," he says, "it needs to come up with new financial mechanisms to ensure that money will flow to sustainable developers and companies."

From an economic perspective, the most interesting aspect of the energy transition is that one no longer has to pay for fuel and emissions costs. "That is the real revolution," Huisman says. "Massive investments are needed to get to that point and, at the moment, money doesn´t always flow in the right direction."

Financing: a raw material for the energy transition

Interview with Dr. Ronald Huisman

MORE THAN PROFITABILITY

In his research, Huisman analyses the mechanisms of price setting as well as the projected returns on investment. He is convinced that a sustainable energy system could become competitive more quickly by reorganising how it is financed. "Don't forget that, back in 2007 and 2008, the oil prices dropped from 140 to 40 dollars a barrel in only six months' time," he says. "In April 2020, we even had negative oil prices. All in all, the returns on investment on fossil fuels simply aren´t that high anymore."

As a result, there is an ongoing trend among some of the big investment funds, such as BlackRock, to shift towards impact investments - not only focussing on financial returns, but also on generating a positive and measurable social and environmental impact. Huisman: "But there is always the pressure to guarantee certain returns to institutional investors who are, after all, responsible for the pensions of millions of people."

REASSESSING ENERGY MARKETS

Huisman is convinced that, in the long run, sustainable energy production will gain the competitive edge over the continued consumption of oil, coal and gas. "To a certain extent, it is the duty of governments to accelerate this transition," he says. "Not only by subsidizing renewable industries, but also by seriously reassessing how energy markets should function."

Currently, projected energy consumption figures are the main input for assessing profitability in energy markets and, thereby, for guaranteeing investors a sizable return on investment. "Sustainable producers do not have that luxury since energy generated by the sun or wind is free," Huisman says. "But they could, for example, develop flat fee agreements and use these to convince the banks that they will make a profit."

SURPLUS ENERGY

His interest into how to properly allocate energy investments goes even deeper. "We should also take a critical look at how these investments are distributed amongst the various technologies that are needed to achieve the energy transition," Huisman says. "Currently, the focus is on developing solar and wind capacities, incentivising people to buy solar panels and pay them back per unit energy they produce. We seem to forget that we also need to invest in short- and long-term storage capacities such as batteries and hydrogen. If we continue this course, we'll end up having overcapacity on sunny days when demand will be down, and no way to store the surplus."

MICROFINANCING

According to Huisman, such reallocation of investments would require a major change of heart in the financial sector. "Currently, start-ups have great difficulty securing loans," he says. "Take a new battery, for example. The investment needed for its development is typically too small for a large bank to really be interested." He would therefore love for the financial sector to develop microfinancing facilities for smaller energy initiatives, allowing capital to be mobilised for increased solar energy production as well as for electrolysers that produce green hydrogen from renewable energy. "To realise the energy transition, we need updated business models just as much as we need raw materials and technical innovation."

'WE SHOULD TAKE A CRITICAL LOOK AT **HOW INVESTMENTS ARE DISTRIBUTED** AMONGST THE **VARIOUS TECHNOLOGIES** THAT ARE NEEDED TO ACHIEVE THE ENERGY TRANSITION'

Photo Ossip van Duijvenbode

Furthing Reading:

René Kleijn – ***The energy transition: a monumental shift in resources and policies***

- Van den Brink, S., Kleijn, R., Sprecher, B. & Tukker, A. Identifying supply risks by mapping the cobalt supply chain, Resources, Conservation and Recycling, Volume 156, 104743 (2020), doi.org/10.1016/j.resconrec.2020.104743 – link
- Patrahau, I., Singhvi, A., Rademaker, M., van Manen, H., Kleijn, R. & van Geuns, L. Securing Critical Materials for Critical Sectors, Policy options for the Netherlands and the European Union, HCCS Geo-Economics, The Hague Centre for Strategic Studies, December 2020 – link
- Ensuring access to the raw materials for the European Green Deal: A European Call for Action, European Raw Materials Alliance (ERMA) – link
- Who's set to win and lose from the green energy revolution? – The Economist – link

Benjamin Sprecher - ***The geopolitics of raw materials***

- Sprecher, B. et al. Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis. Environ Sci Technol 49, 6740–6750 (2015) – link
- Sprecher, B. et al. Novel Indicators for the Quantification of Resilience in Critical Material Supply Chains, with a 2010 Rare Earth Crisis Case Study. Environ Sci Technol 51, 3860–3870 (2017) – link
- Sprecher, B., Reemeyer, L., Alonso, E., Kuipers, K. & Graedel, T. E. How "black swan" disruptions impact minor metals. Resour Policy 54, 88–96 (2017) – link
- The transition to clean energy will mint new commodity superpowers, The Economist – link

David Peck – ***Material shortages and industrial policies: from past to present***

- Peck, D. A Historical Perspective of Critical Materials: 1939 to 2006. World Sci Ser Curr Energy Issues 85–101 (2019) – link
- Cimprich, A. et al. The role of industrial actors in the circular economy for critical raw materials: a framework with case studies across a range of industries. Mineral Econ 1–19 (2022) – link
- Bakker, C., Hollander, M. den, Peck, D. & Balkenende, R. Circular Product Design: Addressing Critical Materials through Design. World Sci Ser Curr Energy Issues 179–192 (2019) – link
- Recyclen-de-luxe, NRC – link

Jewellord Nem Singh – ***The (local) cost of reducing our dependency on imported raw materials***

- Developmental States beyond East Asia, edited By Jewellord Nem Singh and Jesse Salah Ovadia, published by Routledge – link
- Resource Governance and Developmental States in the Global South, edited by Jewellord Nem Singh and France Bourgouin, published by Palgrave MacMillan – link
- Jewellord Nem Singh, Mining Our Way Out of the Climate Change Conundrum? The Power of a Social Justice Perspective, Wilson Center – link
- Critical Materials for the Energy Transition: Rare Earth Elements, International Renewable Energy Agency – link
- The EU's risky dependency on critical Chinese metals, Deutsche Welle – link

Furthing Reading:

Ester van der Voet – ***Urban mining: raw materials in your back yard and pocket***

- Deetman, S., Boer, H. S. de, Engelenburg, M. V., Voet, E. van der & Vuuren, D. P. van. Projected material requirements for the global electricity infrastructure – generation, transmission and storage. Resour Conservation Recycl 164, 105200 (2021) – link
- Oorschot, J. van, Sprecher, B., Roelofs, B., Horst, J. van der & Voet, E. van der. Towards a low-carbon and circular economy: Scenarios for metal stocks and flows in the Dutch electricity system. Resour Conservation Recycl 178, 106105 (2022) – link

Olindo Isabella – ***Recycling solar panels: a solution waiting to happen***

- Han, C. et al. Controllable Simultaneous Bifacial Cu-Plating for High-Efficiency Crystalline Silicon Solar Cells. Sol Rrl 2100810 (2022) – link
- Han, C. et al. Towards bifacial silicon heterojunction solar cells with reduced TCO use. Prog Photovoltaics Res Appl (2022) – link
- Ziar, H., Manganiello, P., Isabella, O. & Zeman, M. Photovoltatronics: intelligent PV-based devices for energy and information applications. Energ Environ Sci 14, 106–126 (2020) - link
- Calcabrini, A. et al. A fully reconfigurable series-parallel photovoltaic module for higher energy yields in urban environments. Renew Energ 179, 1–11 (2021) – link
- De toekomst van 'solar everywhere', TU Delft – link
- Circulariteit, op weg naar 2050?, Chapter 'Solar Energy', edited by P. Luscuere, published by TU Delft Open – link
- TU Delft: 'We creëren cluster dat meer balans brengt op weg naar zelfvoorzienend Europa', Solar Magazine – link

Ronald Huisman – ***Financing: a raw material for the energy transition***

- Koolen, D., Huisman, R. & Ketter, W. Decision strategies in sequential power markets with renewable energy. Energ Policy 167, 113025 (2022) – link
- Huisman, R. & Stet, C. The dependence of quantile power prices on supply from renewables. Energ Econ 105, 105685 (2022) – link
- Huisman, R., Kyritsis, E. & Stet, C. Fat Tails due to Variable Renewables and Insufficient Flexibility: Evidence from Germany. Energy J 43, (2022) – link
- Hoe lang zal de energieprijs extreem hoog blijven?, MeJudice – link
- De hele wereld duikt ineens in waterstof, NRC – link
- Waarom huishoudens in de kou zitten, terwijl grote bedrijven profiteren van de lage gasbelasting – Nederlands Dagblad – link

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