FutuRaM

Future availability of secondary raw materials

Re-mining the mine: critical raw material availability in historic mining waste

6th September 2023

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

EU Framework Programmes

Funded by the European Union

Agenda

1. Introduction to FutuRaM - James Horne, WEEE Forum
2. Mining waste: the opportunities & challenges - Erika Ingvald, SGU, Geological Survey of Sweden
3. Historical mining wastes in France, from environmental monitoring to identify potential recovery sites – Daniel Monfort, BRGM, Geological Survey of France
4. Mine waste in West Balkan area and mineral resource potential in Bor tailings – Jasminka Alijagić, GeoZS, Geological Survey of Slovenia
5. Secondary mineral resources in Finland and the Otanmäki tailings case site – Teemu Karlsson, GTK, Geological Survey of Finland
6. Questions
7. Round up

FutuRaM

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Introduction to FutuRaM

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weeeforum

Background

- EU wishes to increase its resilience in raw materials supply chains for EU industry and strategic sectors to enable the green and digital transition

- Reduce current over-dependence on a few third countries for critical raw materials

e.g. Russia is among the top 3 global producers of 13 critical raw materials - 42% of palladium is supplied by Russia

- Boost domestic production of primary and secondary raw materials with a particular focus on critical raw materials

FutuRaM Summary

- No structured & harmonised knowledge on availability and recoverability of secondary raw materials.
- Develop knowledge on the availability and recoverability of secondary raw materials within the EU, special focus on CRM. From now to 2050.
- UN Framework Classification (UNFC) not generally applied to SRM projects.
- Enable fact-based decision making for their exploitation in the EU and third countries through UNFC applied to SRM projects.
- No central knowledge base.
- Disseminate this information via a Secondary Raw Materials Knowledge Base.

FutuRaM Waste Streams

Batteries

Electrical and Electronic Equipment

Vehicles

Slags and Ashes

Mining Waste

Construction and Demolition Waste

Expected Results – SRM/CRM stocks and flows

Outputs

Secondary Raw Materials Knowledge Base

Current and future demand estimates, and supply risks of SRMs and CRM

Three future pathways to 2050 covering six waste streams for EU

FutuRaM SRM-KB

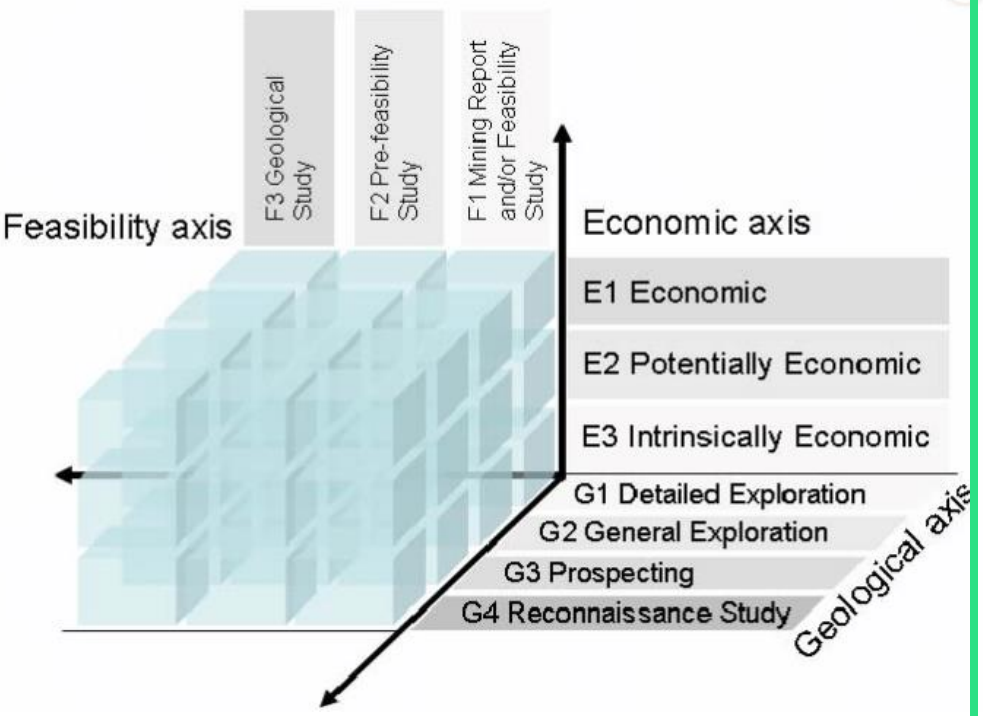
Providing dynamic visualisation tools and analysis

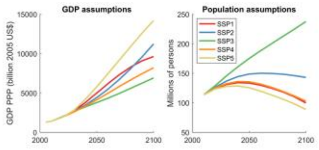
Expected Results – UNFC

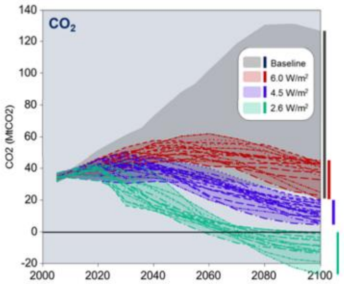
UNFC methodology

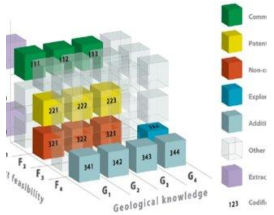
Development, and testing of UNFC for SRMs with 19 case studies resulting in robust methodology

Economic | Technical | Geopolitical | Regulatory | Social | Environmental









Standing on the shoulders…

FutuRaM builds on the knowledge and results of previous projects, initiatives and tools

DUNCAN KUSHNIR
Data | Science | Engineering

unitar
United Nations Institute for Training and Research

mace

REPIC
WEEE | BATTERIES | PACKAGING

Geoscience for a sustainable Earth
brgm

NEW BOLIDEN

TU berlin

F

Stiftung
GRS Batterien

weeeforum

LOVISAGRUVAN

GeoZS
Geološki zavod Slovenije

emr
METAL RECYCLING REIMAGINED

LMU
LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Universiteit Leiden
Institute of Environmental Sciences

Erion Weee

WEEECycling

GTK

SGU
Geological Survey of Sweden

RECHARGE
ADVANCED RECHARGEABLE & LITHIUM BATTERIES ASSOCIATION

ecosystem
recycler c'est protéger

CHALMERS
UNIVERSITY OF TECHNOLOGY

spi
Sociedade Portuguesa de Inovação

Empa
Materials Science and Technology

BGR
Federal Institute for Geosciences and Natural Resources

vito

FutuRaM Summary

4 year project

June 2022 – May 2026

Consortium of 28 partners
from 11 countries

Horizon Europe – Research and Innovation

European Health and Digital Executive Agency (HaDEA)

Contact details

www.futuram.eu

@FuturamProject

FutuRaM project

FutuRaM

Future availability of secondary raw materials

Mining Waste – Opportunities and Challenges

2023-09-06, WRF

Ronald Arvidsson, Roger Hamberg, Anna Ladenberger, Erika Ingvald
SGU, Geological Survey of Sweden

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
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EU Framework Programmes

Funded by the European Union

SGU Geological Survey of Sweden

Background

Work in Sweden

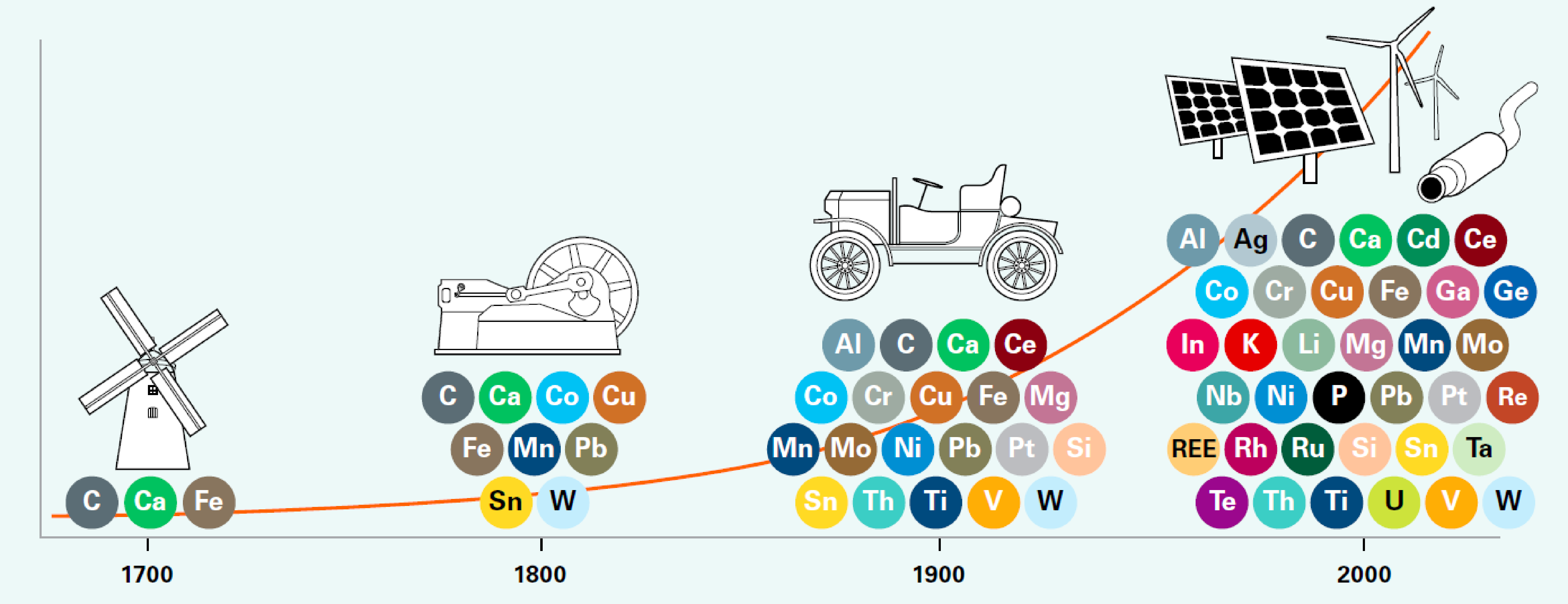
Opportunities and challenges

Conclusions

01

Background

Consumption of mineral raw materials over time

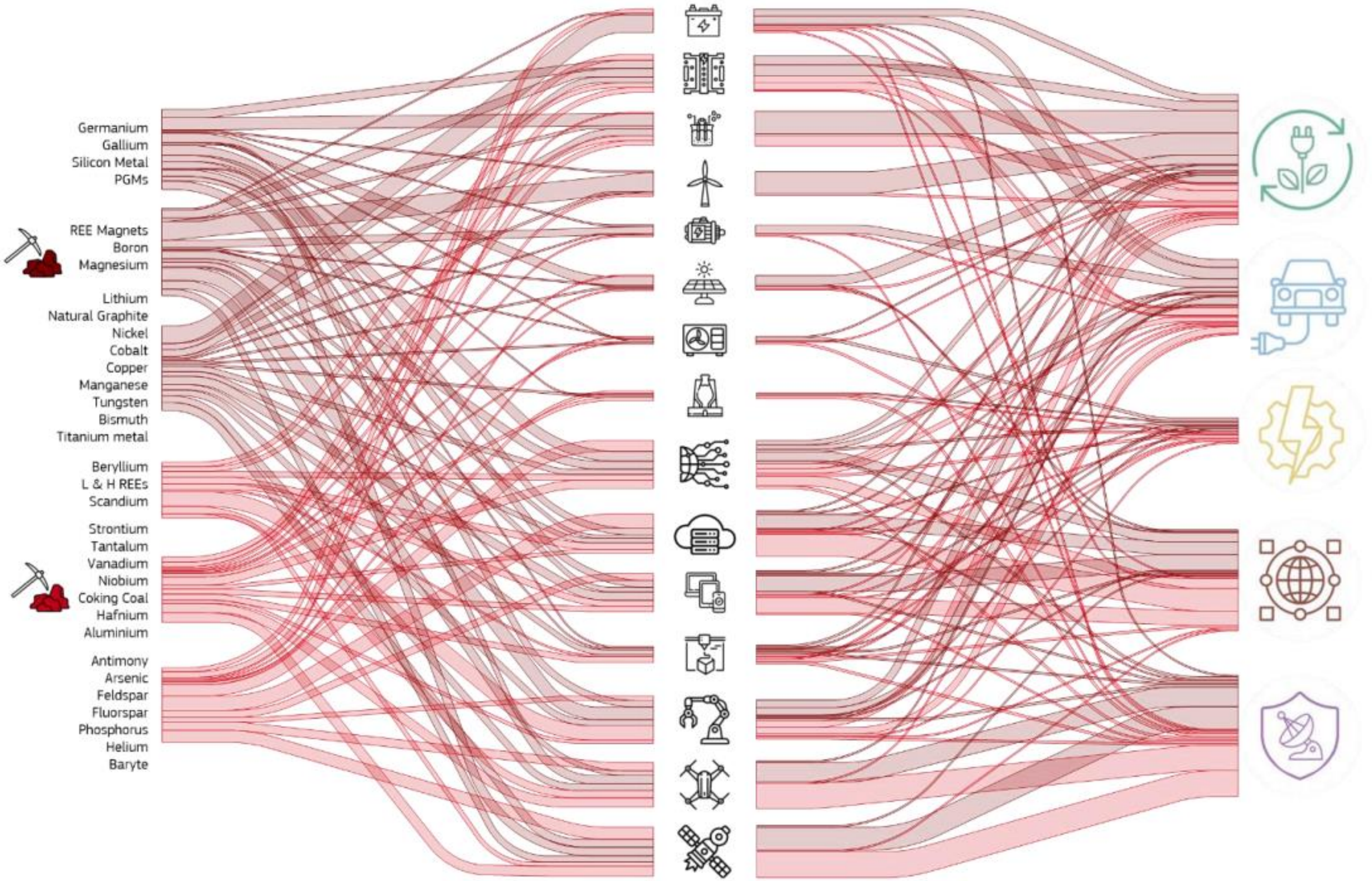


Source: Achzet et al (2009)

The green transition

Photo: Kaj Lax

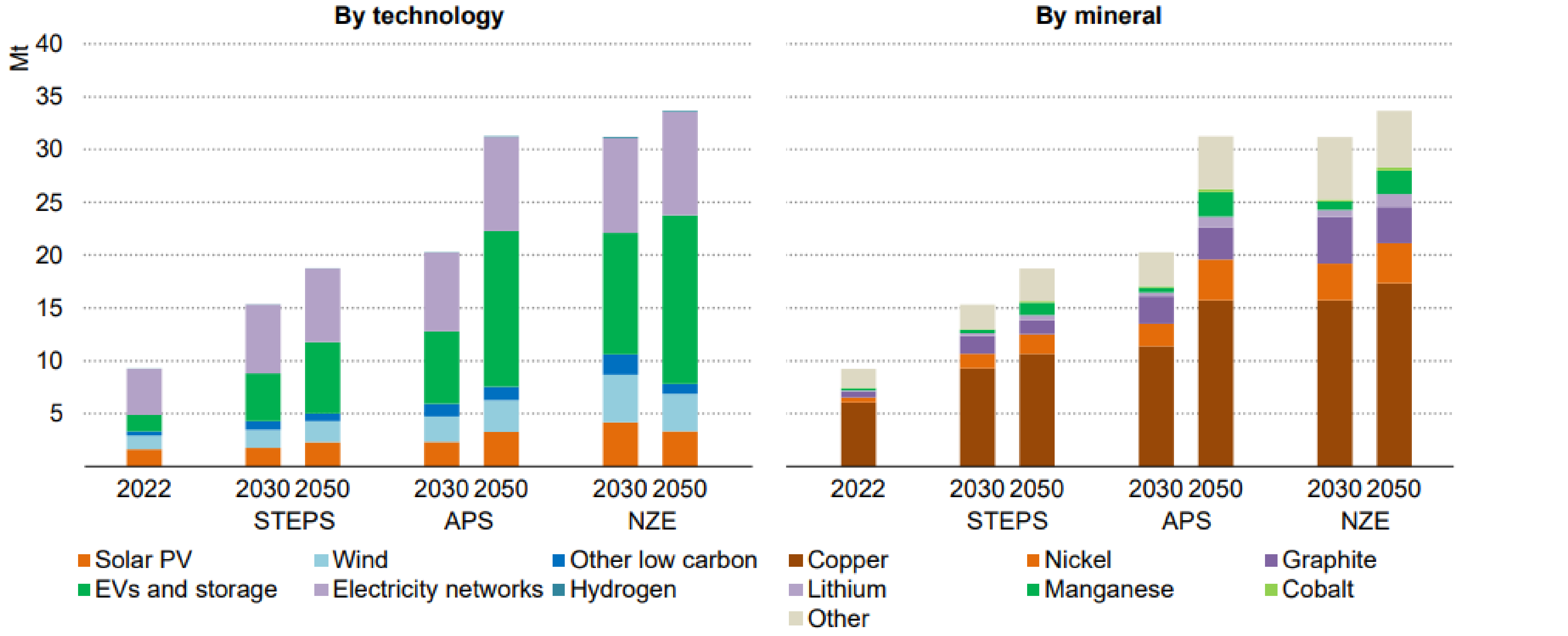
2023



JRC 2023

Critical minerals demand for clean energy is set to grow by up to three-and-a-half times over the period to 2030 as the world moves through energy transitions

Mineral requirements for clean energy technologies by scenario

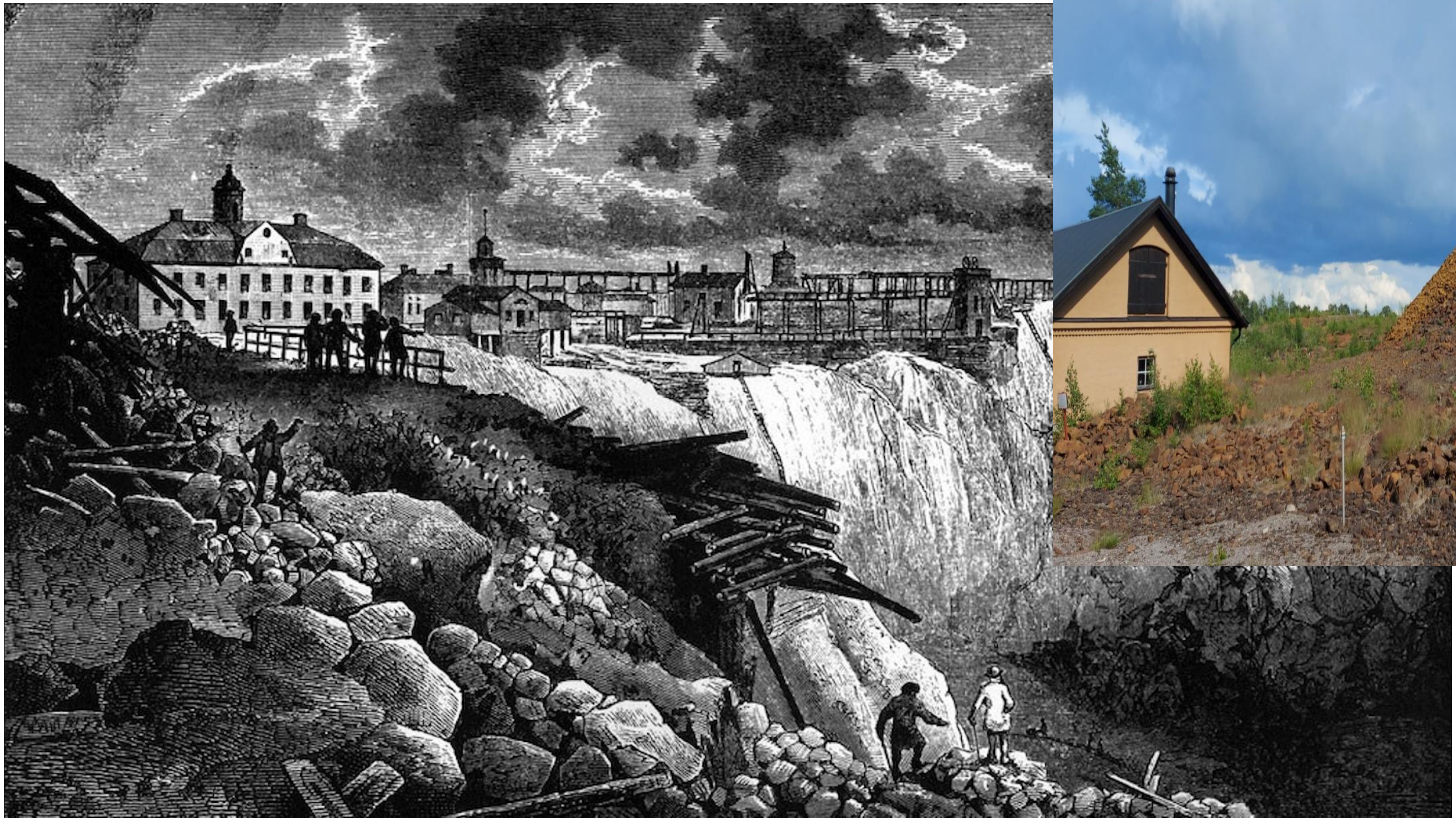


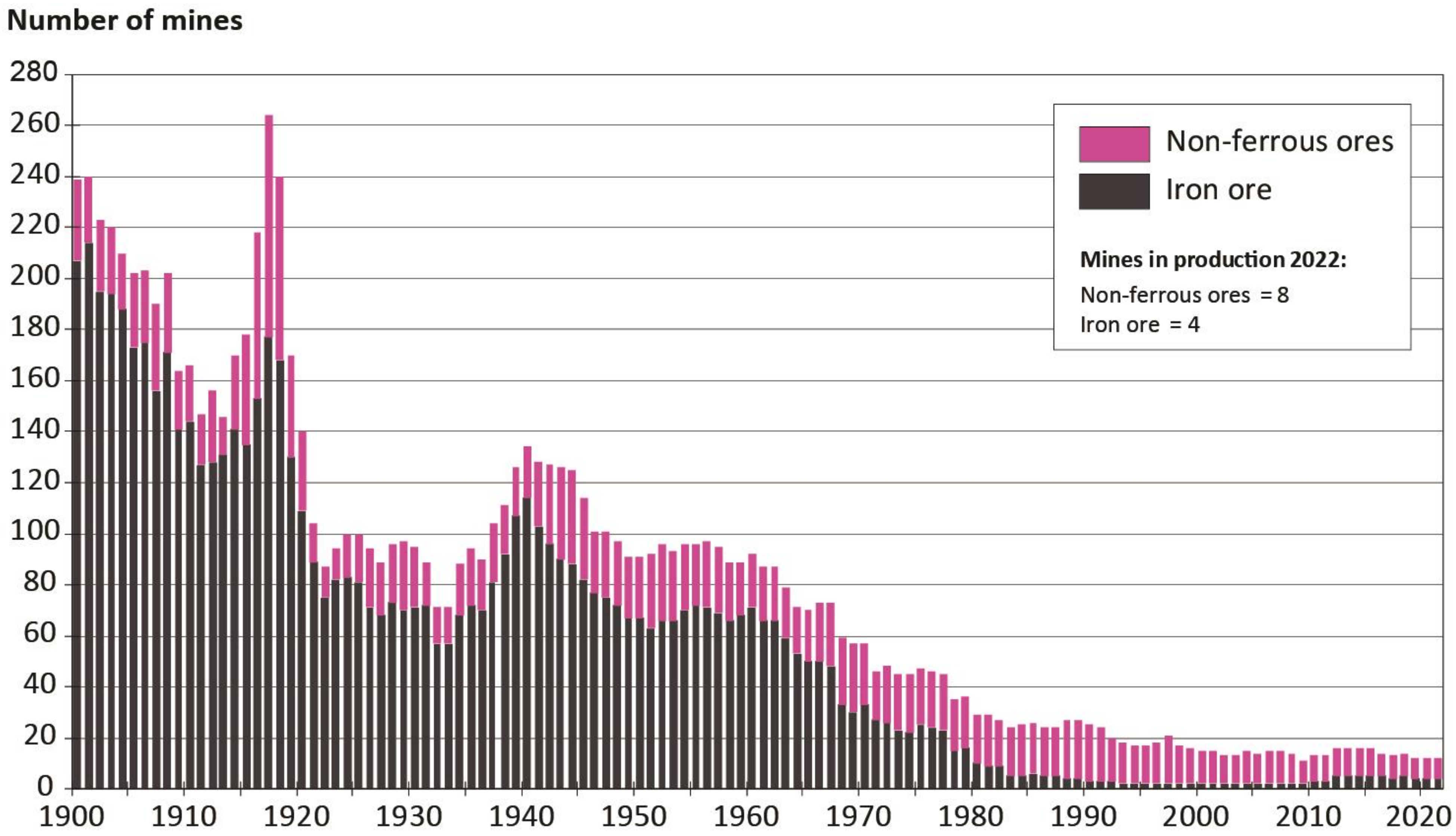
Notes: STEPS = Stated Policies Scenarios; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Includes most of the minerals used in various clean energy technologies, but does not include steel and aluminium.

02.

Work in Sweden

Mining for 2400 years…





Number of mines in production in Sweden 1900–2022.

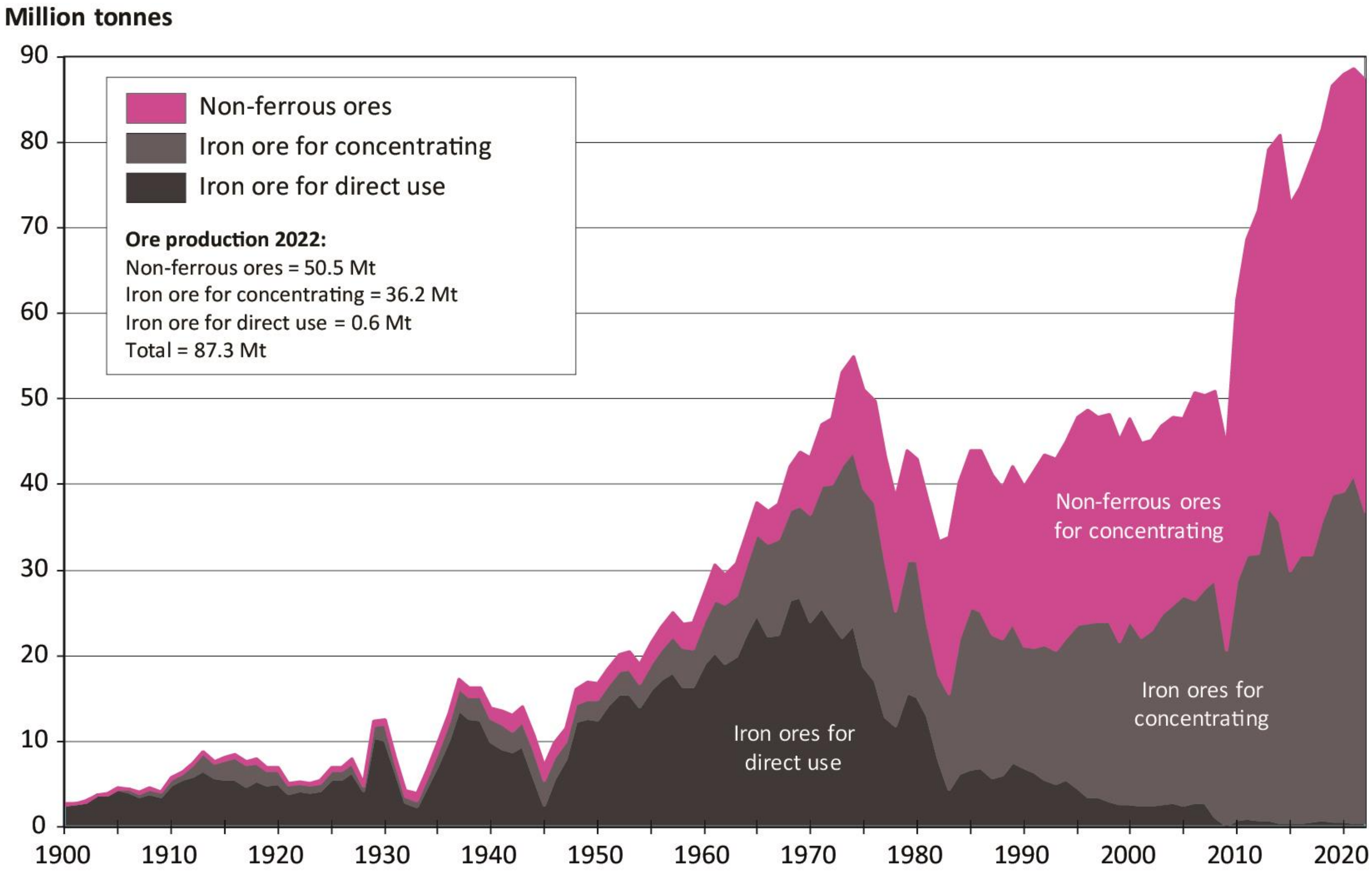
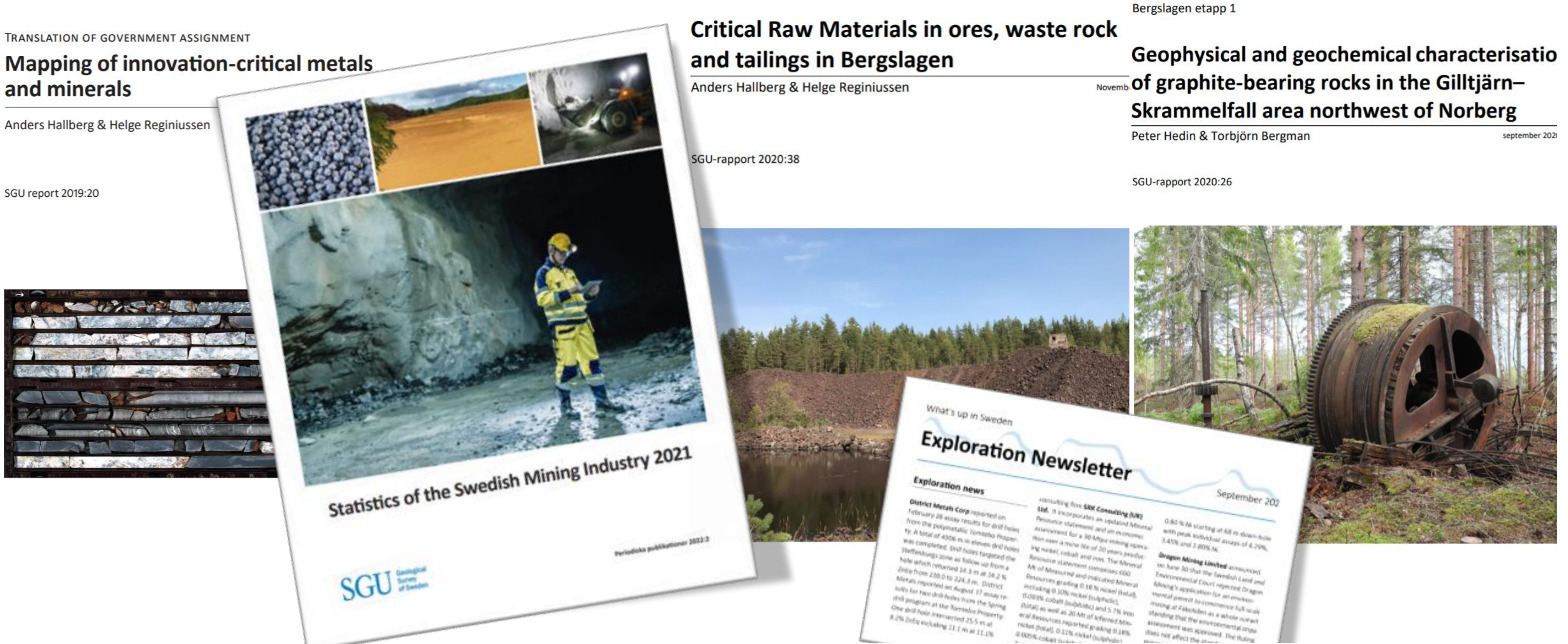
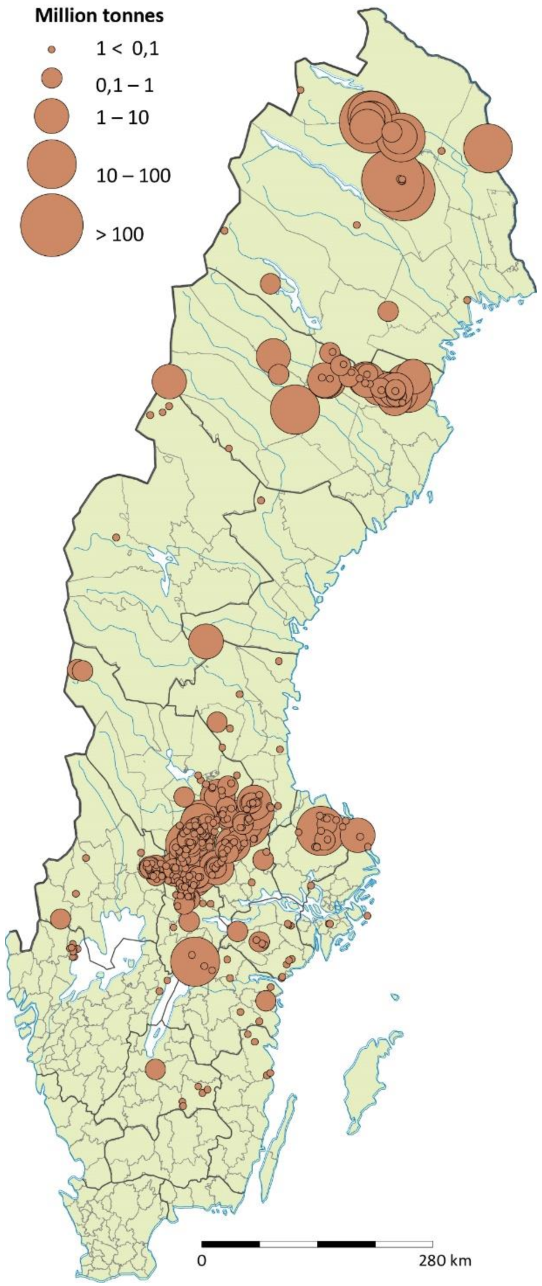


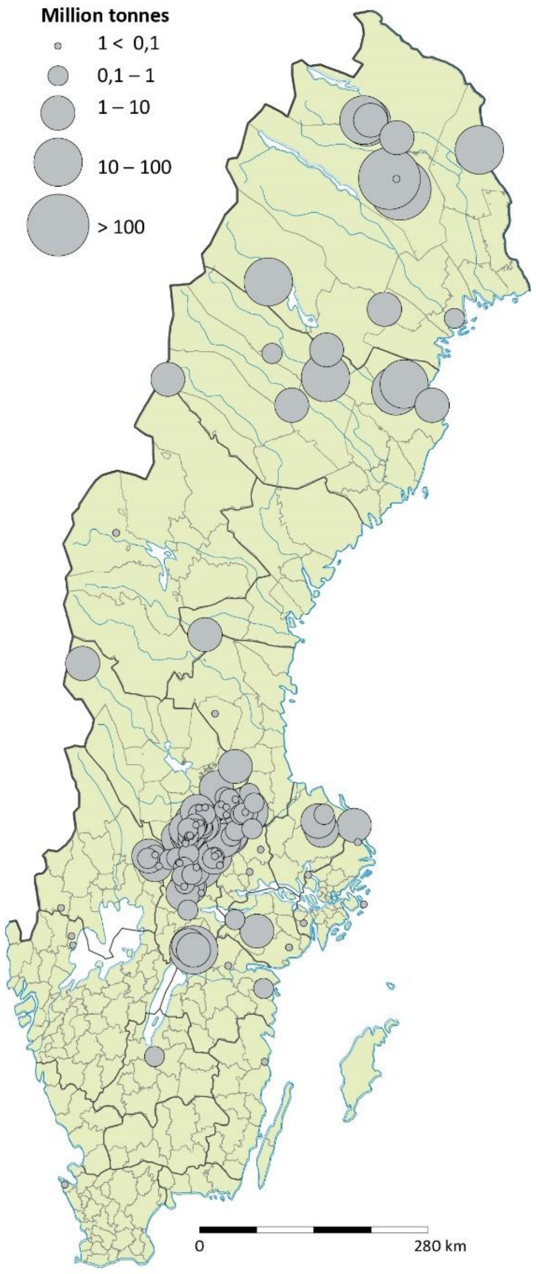
Figure 3. Production of ore in Sweden 1900–2022.

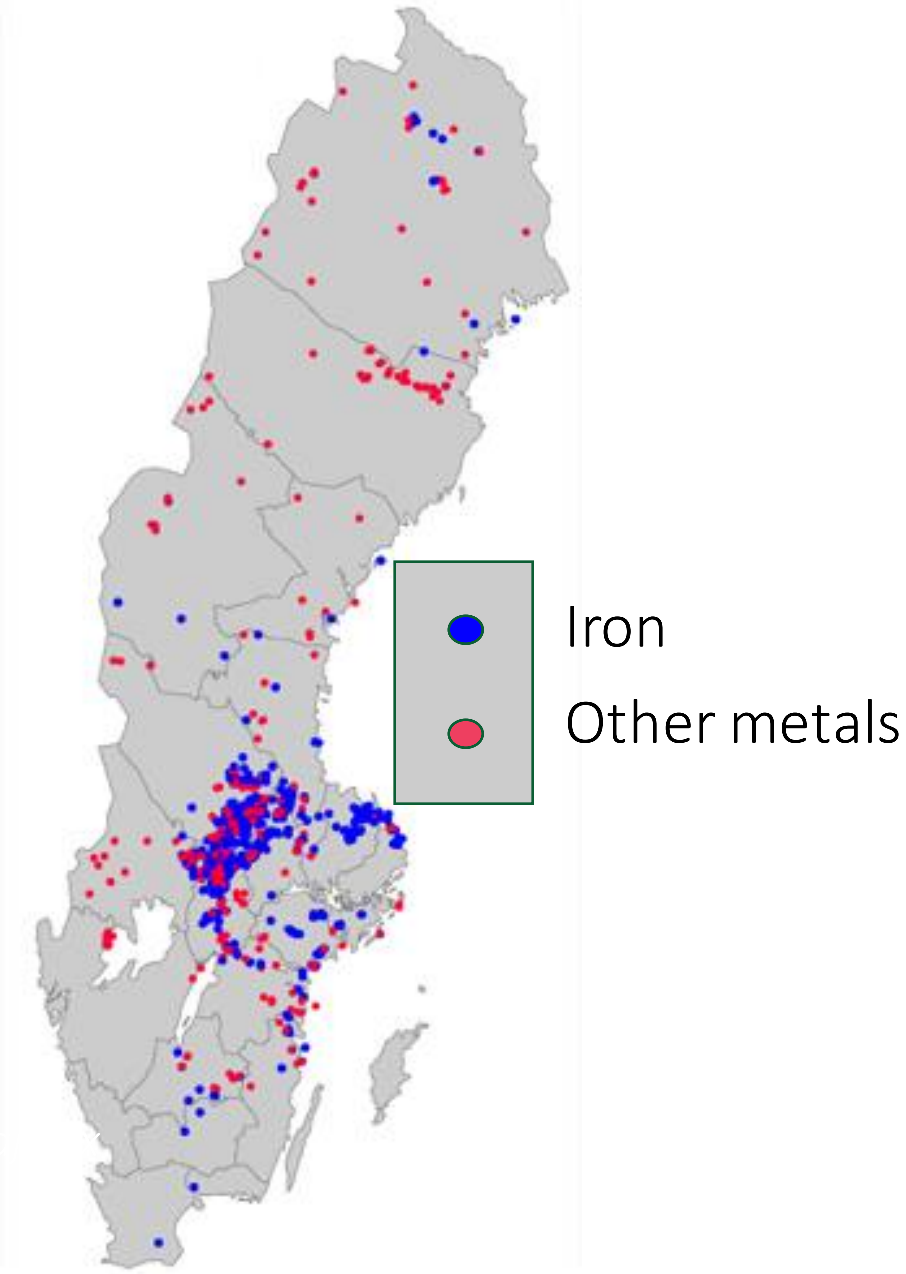
Work on mining waste for a decade



Waste rock, tailings and old mines







Over 3000 mining sites in Sweden

Mission from the government development of UNFC and characterization of mining waste

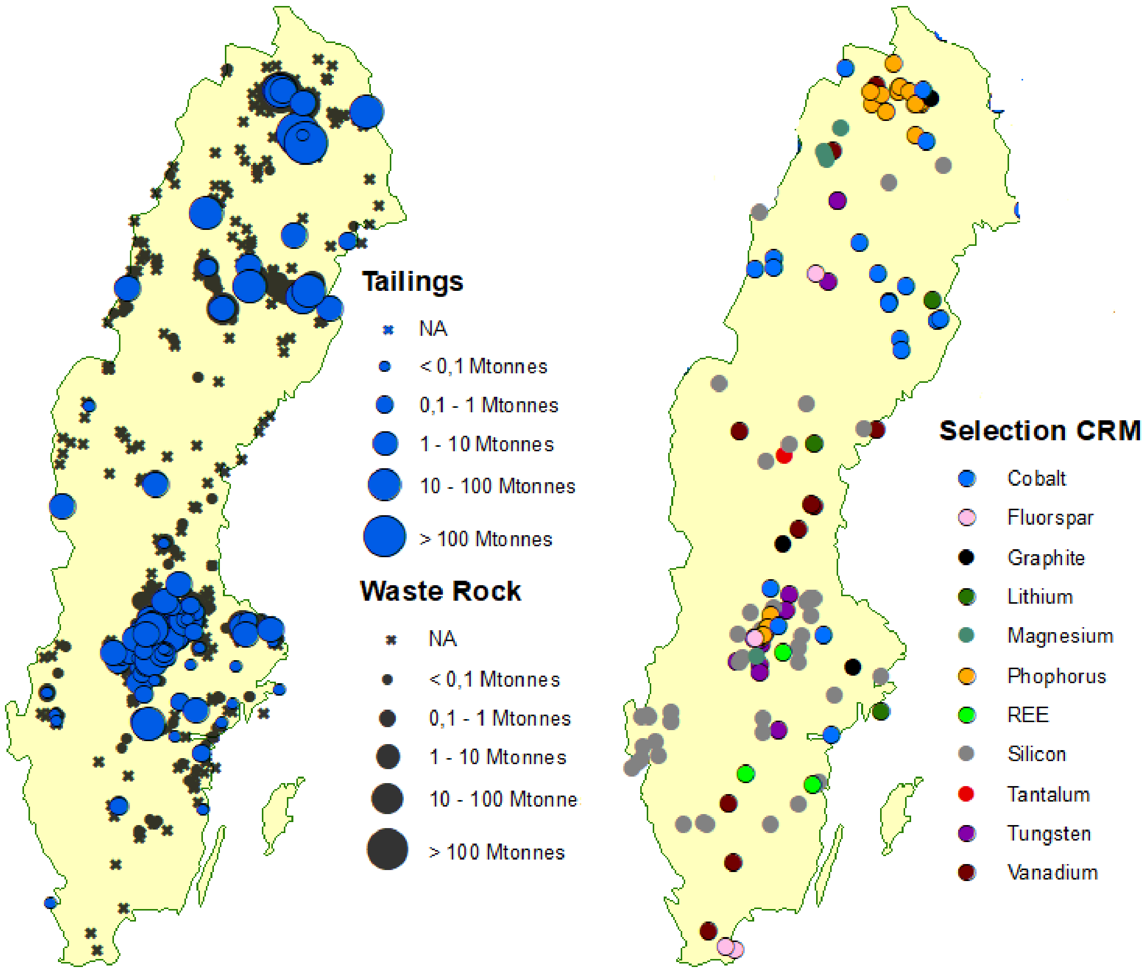
UNFC G-axis

- G4 - Some data >1000 sites
- G3-G4 Tailings and Waste Rock
- G1-G2 One example

F – axis – example to follow (F2)

E-axis – E3 and E2 (one case) hearing with industry and authorities

- Operating mine resources still part of the mining process
- If closed tailings/waste rock sites – access only if control/ownership – for permitting



Methods

Sampling – standardised procedures

- tailings drilling and
  surface samples
- waste rock sampling
- Characterization – elements, mineralogy, grade resources

Volume

- area
- depth (drilling and geophysics)

Estimate of resources

- grades and tonnage

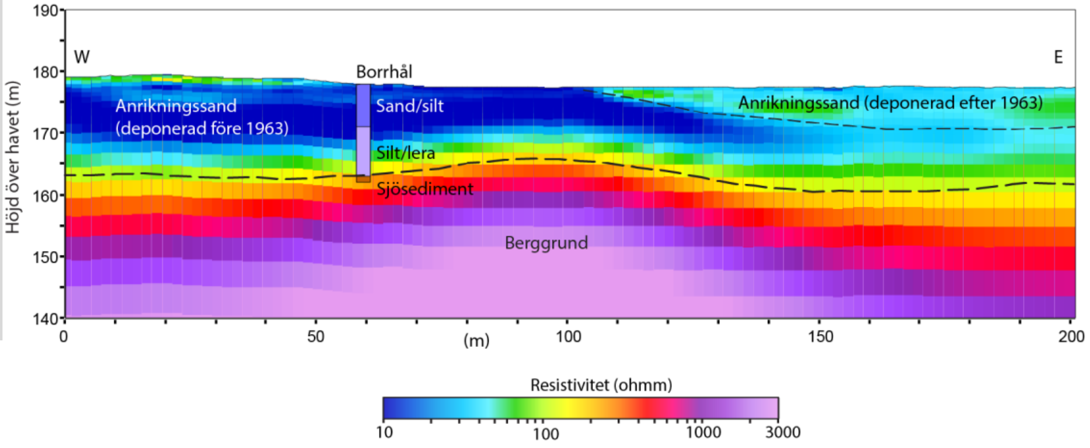
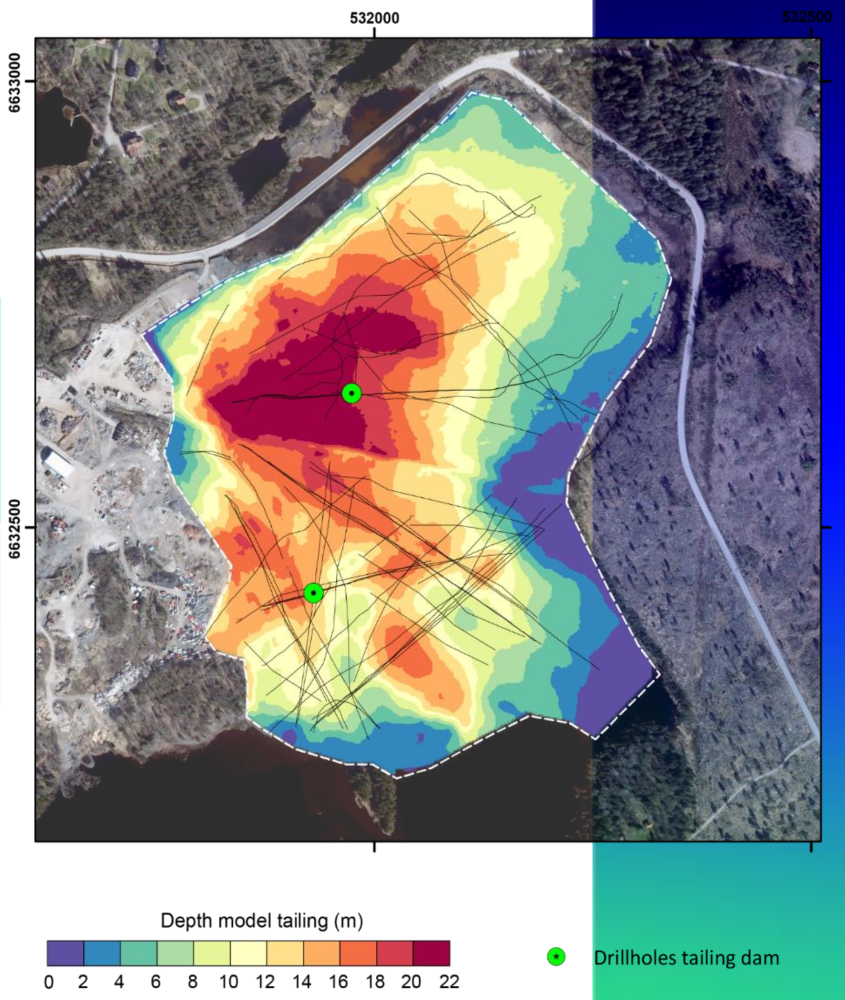



Photo Patrick Casey

Bäckegruvan resources

Average concentrations and tonnage in the tailing:

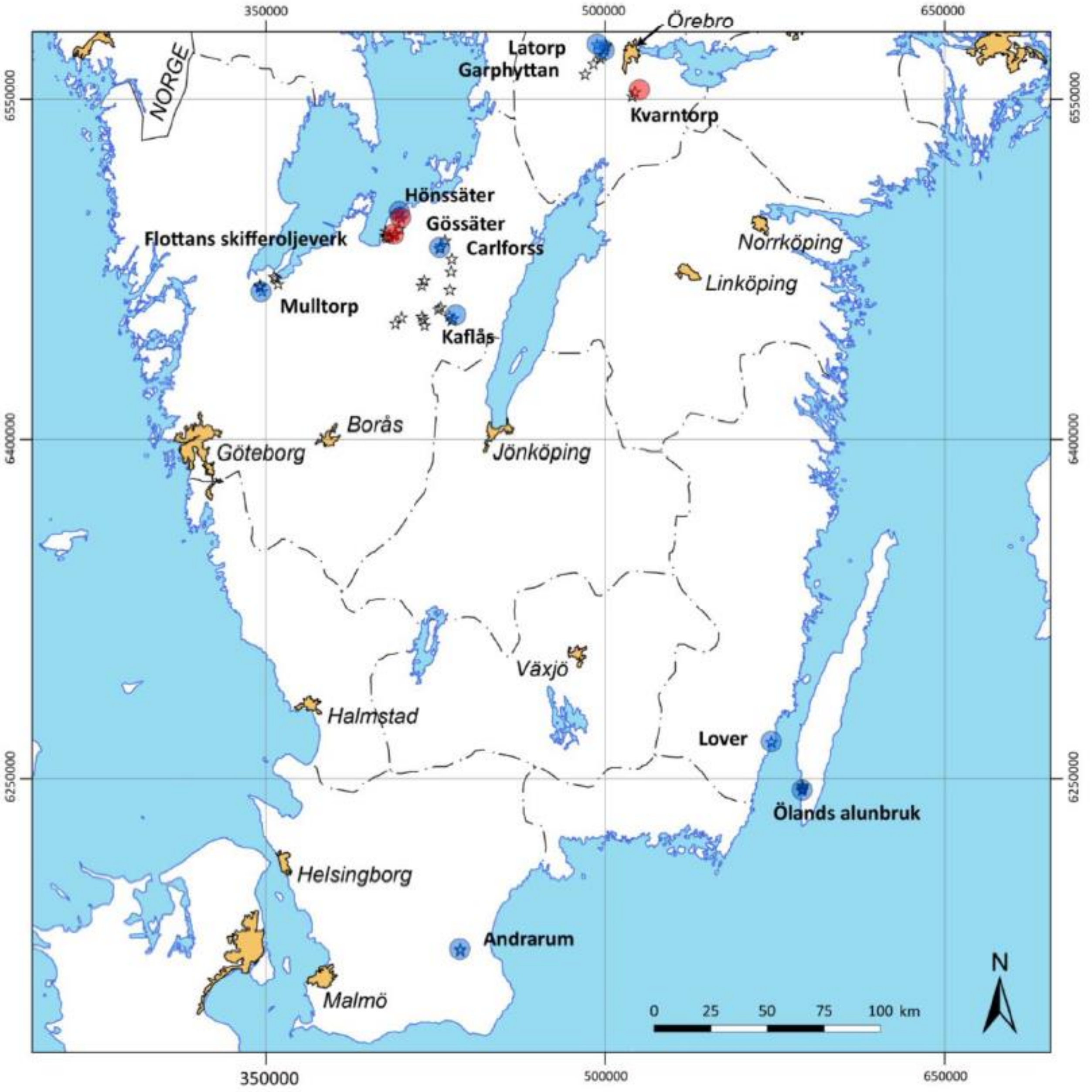
Total tailings, 5,3 mt	Fe %	Ba ppm	Cu ppm	Co ppm	Mo ppm	REE+Y ppm	Rb ppm
Halt	13	6 568	1 191	321	47	1 077	108
Tonnage	665 078	34 810	6 313	1 702	248	5 706	573



Mining waste - Sweden

Results – burned alum shale

- Vanadium 600 – 1300 ppm, depending on area. Molybdenum 100-200 ppm, plus a range of other elements (Ni, U, Cu, P and others) – but in general low tonnage.



Tailings

Provtagningsobjekt	Sand	Be	Bi	Co	Ga	Ge	Hf	In	Li	Nb	P	PGM	REE+Y	Sb	Sc	Sr	Ta	Ti	V	W	Fe	Ni	Cu	Pb	Zn	Ag	Au
Adak	5 400 000	1,0	41	850	87	1,1	1,4	3,8	55	1,7	3 100	<0,032	550	100	97	420	2,2	18 000	400	70	540 000	70	10 000	290	2 500	7,99	0,999
Blaiksjön	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Blötberget Glaningen	300 000	0,9	0,2	6,0	4,5	0,2	1,4	0,0	8,4	3	3 000	<0,002	370	0,1	2,8	10	0,3	330	88	5,6	40 000	12	1,6	2,8	17	0,01	0,005
Blötberget Norberget	4 400 000	7,8	1,4	43	67	1,9	18	0,3	66	49	28 000	<0,026	5 200	3,0	36	280	6,9	3 000	940	58	470 000	104	37	34	190	0,34	0,108
Bäckegruvan	5 300 000	18	290	1 700	68	11	20	17	120	54	610	0,032	5 700	5,0	21	180	4,0	2 900	30	280	670 000	24	6 300	24	180	2,36	0,372
Grängesberg HT*	8 400 000	56	3,1	170	200	9,4	20	1,9	820	130	81 000	<0,050	16 000	13	110	290	27	11 000	4 600	160	1 900 000	320	45	54	1 200	0,11	0,012
Grängesberg JMD*	2 550 000	12	1,4	37	50	2,2	7,8	0,2	290	55	58 000	<0,015	4 700	2,2	30	140	11	2 500	940	68	380 000	62	20	20	170	0,03	0,003
Grängesberg SD*	3 120 000	4,2	0,8	40	50	1,2	12	0,2	160	71	29 000	<0,019	2 800	1,8	48	230	11	4 000	410	29	230 000	67	14	28	140	0,07	0,018
Idkerberget	50 200	<0,1	<0,1	1,6	1,2	0,0	0,2	0,0	1,1	0,6	720	<0,001	57	<0,1	0,8	8,0	<0,1	[illegible]	17	0,2	6 400	1,9	1,3	0,7	3,7	0,00	<0,001
Intrånget	2 650 000	5,8	130	100	32	3,9	6,0	5,1	21	12	1 000	<0,016	540	0,6	28	220	[illegible]	3 900	150	180	300 000	54	4 000	540	2 600	4,12	0,342
Kalvsbäcken	280 000	0,1	0,3	1,7	2,7	0,1	0,6	0,0	2,3	1,4	22	<0,002	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7,5	7,5	28 000	2,1	190	1 400	2 100	12,2	0,017
Kaveltorp	500 000	1,5	11	1,7	6,0	0,3	0,8	0,1	5,7	2,6	47	<0,003	53	[illegible]	[illegible]	9,3	0,3	100	5,0	29	25 000	1,7	610	3 800	4 600	3,16	0,036
Källfallet	940 000	7,2	20	22	30	1,2	4,5	0,4	10	11	110	<0,006	[illegible]	[illegible]	3,1	8,7	0,7	470	5,0	78	125 000	11	290	4,4	10	0,06	0,026
Laisvall	60 000 000	14	1,9	64	68	3,2	27	5,5	260	11	7 900	<0,360	[illegible]	75	52	4 700	<0,6	5 300	300	14	410 000	240	360	230 000	62 000	<0,60	<0,060
Långnäs	800 000	0,3	25	21	6,0	0,8	0,9	1,6	2,1	2,2	120	<0,005	81	0,9	3,3	42	0,1	580	19	35	120 000	4,9	200	160	440	1,74	0,101
Lövås	285 000	0,1	0,8	12	2,7	0,1	0,5	0,1	0,8	0,9	79	<0,002	28	10	2,1	17	<0,1	310	14	2,0	37 000	2,4	88	1 400	2 300	2,99	0,010
Nyberget	1 400 000	0,8	19	17	12	0,9	1,4	1,8	2,1	3,5	190	<0,008	350	0,3	3,3	40	0,1	520	16	25	140 000	4,4	140	18	140	0,05	0,006
Stollberg	2 800 000	5,0	7,1	10	53	0,9	6,2	2,3	15	15	610	<0,017	520	40	7,6	73	1,6	1 100	37	62	300 000	13	440	8 600	13 600	24,8	0,054
Svärdsjö	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vassbogruvan	4 430 000	0,3	0,1	10	6,1	<0,2	35	0,2	2,9	12	850	<0,027	240	5,4	5,1	690	1,3	5 400	35	5,3	26 000	8,1	63	14 000	2 000	6,58	0,005
Vintjärn	3 250 000	2,6	8,3	36	30	0,4	19	5,3	35	32	1 700	<0,020	770	<0,2	21	80	2,0	4 400	41	12	320 000	51	320	50	810	0,15	0,062
Viscaria	12 000 000	5,9	62	1 700	120	3,5	6,7	7,9	320	1,0	18 000	<0,072	4 300	6,9	110	590	0,1	24 000	1 900	8,0	1 200 000	1 500	36 000	1 700	33 000	11,4	0,611
Yxsjöberg MT	2 200 000	290	1 000	55	50	6,4	4,9	8,1	13	13	400	<0,013	360	0,9	13	75	0,7	1 600	82	2 000	290 000	23	1 029	11	610	0,61	0,289
Totalt	**121 100 000**	**430**	**1 700**	**4 900**	**940**	**48**	**190**	**62**	**2 200**	**480**	**240 000**	**0,032**	**49 000**	**280**	**600**	**8 100**	**70**	**90 000**	**10 000**	**3 100**	**7 600 000**	**2 600**	**60 000**	**260 000**	**130 000**	**79**	**3,1**

*HT = Hötjärnen, JMD = Jan-Matsdammen, SD = Svandammen, MT = Morkulltjärnen

Gruva	Varp	Be	Bi	Co	Ga	Ge	Hf	In	Li	Nb	P	PGM	REE+Y	Sb	Sc	Sr	Ta	Ti	V	W	Fe	Ni	Cu	Pb	Zn	Ag	Au
Baggetorp	270 000	0,1	13	2,2	4,3	0,1	1,3	<0,1	3,6	2,8	57	0,002	43	<0,1	2	29	0,3	480	12	92	6 600	3	39	2	13	0,09	0,001
Basttjärn	2 570 000	2,3	8,1	20	38	0,7	10	0,5	25	17	322	<0,015	290	1	5	47	1	1 200	24	25	350 000	8	420	300	540	1,13	0,010
Bjurfors	30 900	<0,1	0,3	1,9	0,7	<0,1	0,2	0,1	0,4	0,2	3,2	<0,001	5	0,1	0,2	1	<0,1	47	1	0,1	3 600	0,1	200	1	62	0,08	0,001
Blötberget	4 200 000	4,3	0,5	53	68	1,2	20	0,2	57	[illegible]	11 000	<0,025	2 500	3	22	260	7	3 400	1 100	50	660 000	90	24	28	120	0,04	0,008
Bäckegruvan	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grängesberg	6 000 000	10	0,9	110	120	2,0	27	0,2	170	64	24 000	<0,036	3 100	2	59	480	21	11 000	1 500	94	620 000	120	57	46	220	0,07	0,020
Gruvberget	122 000	0,1	0,8	3,1	1,5	<0,1	0,3	<0,1	2,4	0,7	47	<0,001	13	3	1	6	<0,1	240	8	0,5	8 600	2	260	1 200	2 900	3,29	0,017
Guttusjö	140 000	<0,1	<0,1	0,4	0,3	<0,1	4,2	<0,1	0,1	1,8	20	<0,001	20	0,2	0,4	5	0,1	750	4	0,1	1 200	0,3	2	1 600	20	0,28	<0,001
Hällefors silvergruvor	94 000	0,1	0,1	0,7	1,4	<0,1	0,3	0,3	0,6	0,8	18	<0,001	14	5	0,2	3	<0,1	14	3	0,2	9 700	1	11	910	1 300	2,97	0,005
Idkerberget	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kalvsbäcken	140 000	0,1	0,4	1,1	2,1	<0,1	0,5	0,2	1,1	1,0	17	<0,001	24	4	1	3	0,1	120	3	1	13 000	1	200	1 800	5 200	7,21	0,007
Kaveltorp	233 000	0,6	31	1,2	4,6	0,1	0,8	0,1	6,0	2,9	25	<0,001	52	1	1	3	0,5	73	2	6	15 000	1	630	3 600	5 200	3,63	0,036
Kittelgruvan	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Källfallsgruvan	1 070 000	7,7	5,8	16	35	0,6	4,5	0,2	12	12	52	0,006	1 300	0,1	3	7	1	520	6	37	140 000	[illegible]	220	3	9	0,05	0,012
Ljusnarsberg	122 000	0,3	7,4	1,6	1,7	0,1	0,5	0,1	4,7	1,2	13	<0,001	22	<0,1	0,4	1	0,2	38	1	5	23 000	[illegible]	[illegible]	190	290	0,39	0,005
Lainejaur	61 000	<0,1	<0,1	19	0,9	<0,1	0,1	<0,1	1,0	<0,1	33	0,001	5	1	1	12	<0,1	210	5	<0,1	[illegible]	[illegible]	170	2	11	0,11	0,010
Laver	133 000	<0,1	0,2	1,2	2,6	0,1	0,5	0,1	2,2	0,9	24	<0,001	19	0,1	1	25	0,1	130	3	[illegible]	[illegible]	2	590	18	94	1,72	0,006
Lövåsen	55 000	<0,1	5,6	1,7	0,5	<0,1	0,1	<0,1	0,1	0,2	12	<0,001	4	0,5	1	4	<0,1	64	[illegible]	[illegible]	11 000	1	23	340	400	0,48	0,002
Malmkärra	83 000	1,7	0,6	0,6	8,6	0,2	0,2	<0,1	0,8	0,5	8,0	<0,001	460	<0,1	0,3	1	<0,1	[illegible]	[illegible]	17	19 000	2	13	2	4	<0,01	<0,001
Mossgruvan	1 310 000	1,3	1,1	13	24	0,2	5,5	0,2	23	22	430	<0,008	260	0,1	6	71	[illegible]	[illegible]	[illegible]	12	85 000	11	37	21	70	0,04	0,003
Nya Bastnäs	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nävergruvan	644 000	29	76	14	13	0,4	2,7	0,5	5,6	6,5	230	0,004	140	[illegible]	[illegible]	[illegible]	[illegible]	910	64	450	45 000	16	170	2	63	0,05	0,025
Persgruvan	560 000	3,0	10	16	13	0,3	3,1	0,3	4,3	8,7	41	0,003	490	<0,1	[illegible]	2	1	330	5	12	68 000	4	420	2	6	0,04	0,017
Pahtohavare	1 700 000	1,0	<0,1	179	22	0,4	0,4	0,2	42	0,2	1 100	0,016	230	0,2	[illegible]	30	<0,2	4 400	410	<2	170 000	200	8 800	20	54	1,36	0,330
Skytt-Näverberg	171 000	0,1	0,9	6,6	2,5	0,1	0,3	0,1	0,6	0,8	82	<0,001	22	20	1	4	<0,1	170	4	1	13 000	2	820	5 700	15 000	23,9	0,091
Ställberget	5 500 000	11	22	53	72	0,9	18	2,3	29	38	960	<0,033	700	1	17	190	2	3 700	120	17	670 000	45	720	29	250	0,24	0,034
Svärdsjö	210 000	0,1	8,4	3,0	2,4	<0,1	0,3	0,1	0,6	0,8	18	<0,001	16	0,5	1	5	0,1	190	6	0,4	17 000	4	1 500	850	3 800	4,18	0,075
Tomtebo	76 000	<0,1	2,5	5,1	1,0	<0,1	0,1	0,1	0,7	0,3	4,6	<0,001	6	0,2	0,1	1	<0,1	42	4	0,2	9 200	0,1	290	120	110	1,22	0,038
Tunaberg	4 500	<0,1	0,1	0,2	0,1	<0,1	<0,1	<0,1	0,1	<0,1	3,1	<0,001	1	0,0	0,0	0,2	<0,1	5	0,1	<0,1	380	0,1	4	3	29	0,02	<0,001
Vena	13 800	<0,1	1,8	2,1	0,3	<0,1	0,1	<0,1	0,3	0,1	7,5	<0,001	3	0,5	0,2	1	<0,1	35	1	<0,1	600	0,3	40	2	23	0,04	<0,001
Viscaria	4 500 000	1,1	2,4	318	82		10	0,8	180	0,6	2 800	0,038	480	1	150	3	1	10 500	1 300	<5	440 000	500	8 000	470	4 600	3,99	<0,005
Wigström	210 000	6,1	6,2	1,1	5,4	0,2	1,1	0,1	6,3	3,7	29	<0,001	43	0,1	1	5	0,4	170	5	110	12 000	1	3	4	41	0,01	0,002
Åsgruvan	570 000	1,1	0,4	4,8	9,2	0,4	1,5	0,3	1,8	3,8	78	0,003	260	1	3	22	0,3	420	12	26	110 0000	4	79	1	21	0,02	0,001
Östanmossa	okänt	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totalt	30 800 000	82	210	850	530	8,1	110	7,1	580	240	42 000	0,1	10 000	46	330	1 300	39	40 000	4 600	950	3 500 000	1 200	24 000	17 000	41 000	57	0,8

Waste rock

		Average tailings				Average waste rock				Average crust
Magnesium	Mg	4 900	–	110 000	14	7 400	–	70 000	16	21 000
Titan	Ti	700	–	7 500	13	820	–	4 300	16	5 000
Fosfor	P	170	–	16 000	13	120	–	>10 000	16	1 000
Strontium	Sr	29	–	1000	14	46	–	860	16	350
Vanadin	V	26	–	440	14	8,9	–	230	16	150
Litium	Li	4,6	–	38	9	4,9	–	48	12	30

03

Opportunities-Challenges

Mining + Add to myFT

Sweden discovers biggest rare earths deposit in EU

Lapland mine could help reduce Europe's dependence on China imports

Swedish state-owned mining company LKAB already has the largest iron mine in the EU © Jonas Ekstromer/EPA-EFE/Shutterstock

Sam Fleming in Kiruna JANUARY 12 2023

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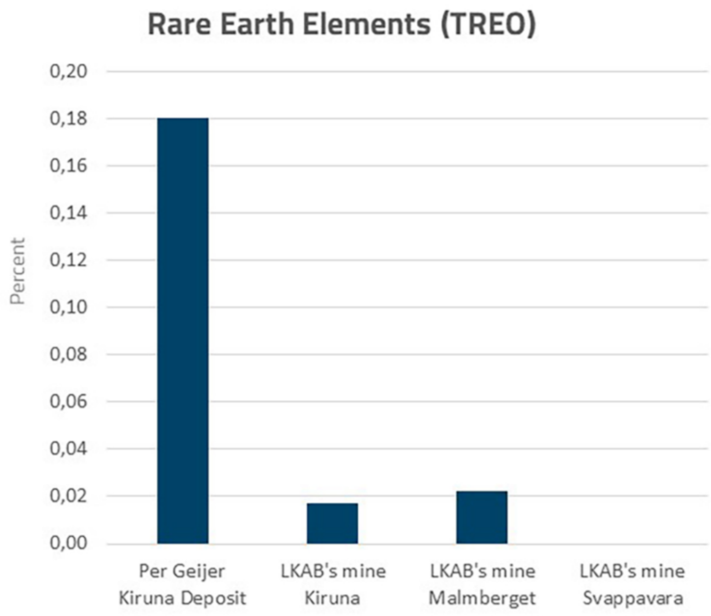
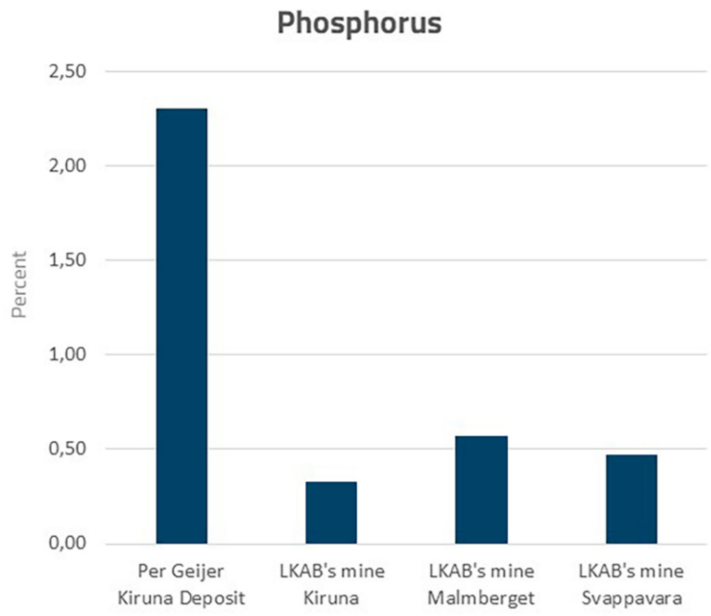
LKAB – Kiruna Phosphate Rock, REE, F, Fe, Gypsum

Large primary resources – totally 4 billion tonne of Fe, REE, P, F

CRM
P 0.02-2.25%
REE 0.01- 0.18%
F

In comparison all apatite abandoned mines in southern Sweden has about
28 Mt of waste
LKAB has more than
1 billon tonne





Source: LKAB 2023-06-12

04

Conclusions

Historic waste: will it contribute to society's needs?

Challenges

- Technology and methodology:
- Often heterogenous material, generations of waste, weathering etc
- Low tonnage, variable grades
- Mineralogy – processes
- Location
- Lost by alternative use
- Improved extraction over time
- Legislation
- Waste areas already restored
- Fluctuating prices

Opportunities

- Modern waste: a different story!
- Some interesting numbers – e g vanadium in steel slag
- Costs for restoration
- Combination with primary mining
- R&D
- …and unexpected opportunities/challenges

Thank you

SGU Geological Survey of Sweden

Futu RaM

Future availability of secondary raw materials

Historical mining wastes in France, from environmental monitoring to identify potential recovery sites

WRF2023 Geneva, 6 September 2023

Daniel Monfort, Françoise Bodénan & Jérôme Jacob

BRGM, French Geological Survey

Schweizerische Eidgenossenschaft
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Introduction

- In mining wastes management we observe a sort of change of paradigm of some ideas. Mining waste management would cover the following ideas

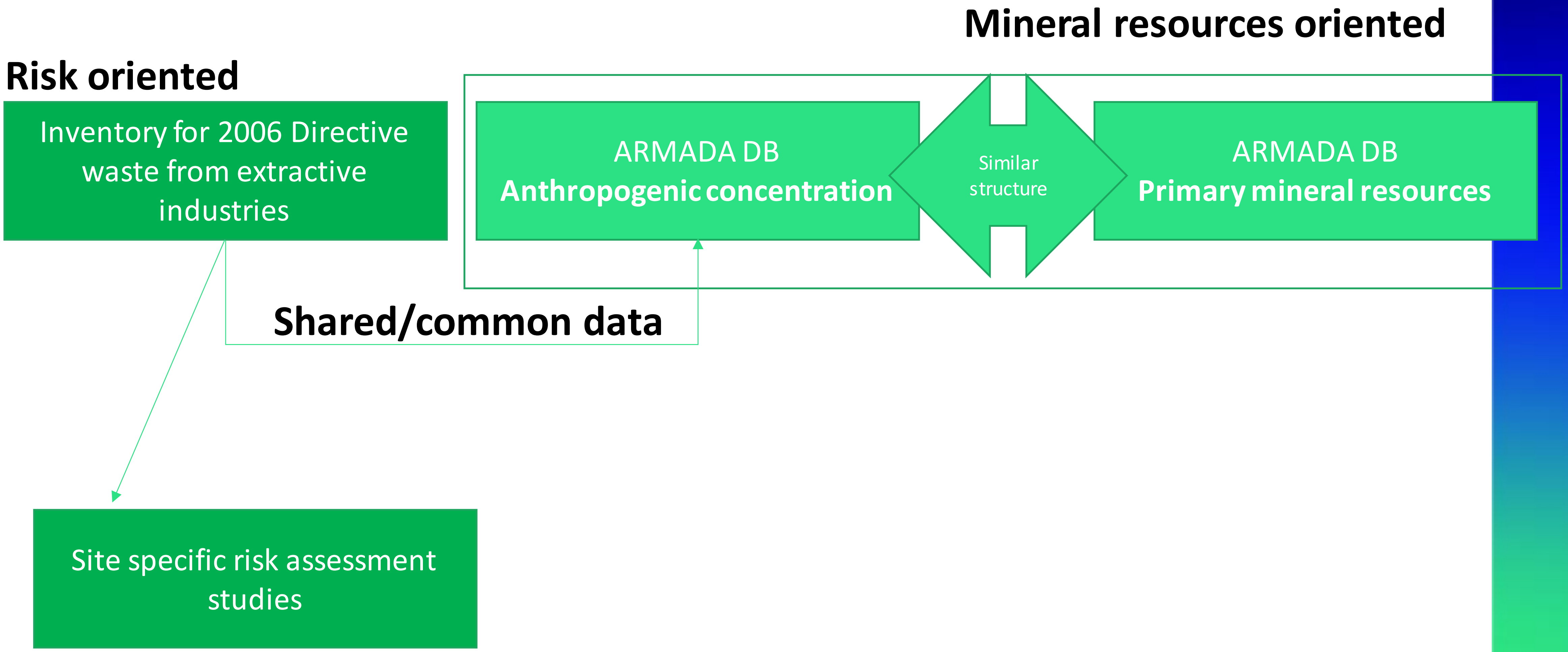
1. Management of environmental and human health risks
2. Circular economy principles & towards zero waste mines
3. EU Critical Raw Materials Act targets

- In France, no major metal mining activity presently. But historical activity during the XXth century

01.

Mining wastes data in France

Mineral and mining wastes databases in France



Environmental monitoring data

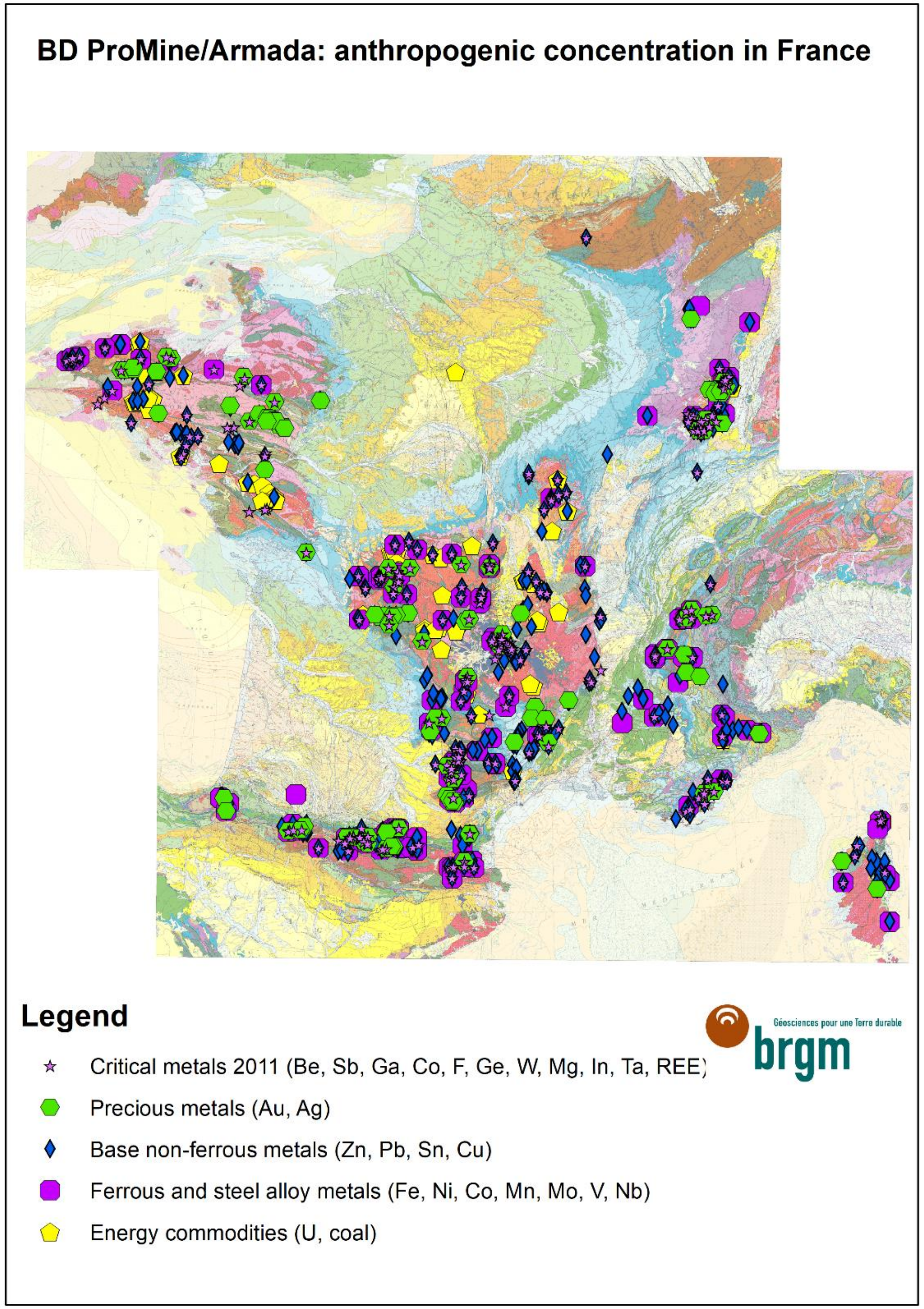
- EU Mining waste Directive 2006/21/CE → inventory of mining wastes sites in each Member State
- In France, a work was done during the 2010-2013s. Inventory of waste sites at regional scale. Environment and human health risk prioritization
- ~200 sites with a detailed assessment (Zibret et al. 2020)
- An environmental monitoring is done in France by a public agency called GEODERIS with the participation of geological survey (BRGM)
- Volumes/quantities: estimated as surface * estimated depth. No geophysics or 3D model
- Chemistry/metals: On field (XRF) and laboratory analysis on a selection of elements
- Reports/data are more or less available

Anthropogenic resources

Mineral resources database including a part for anthropogenic resources ➔ ARMADA database

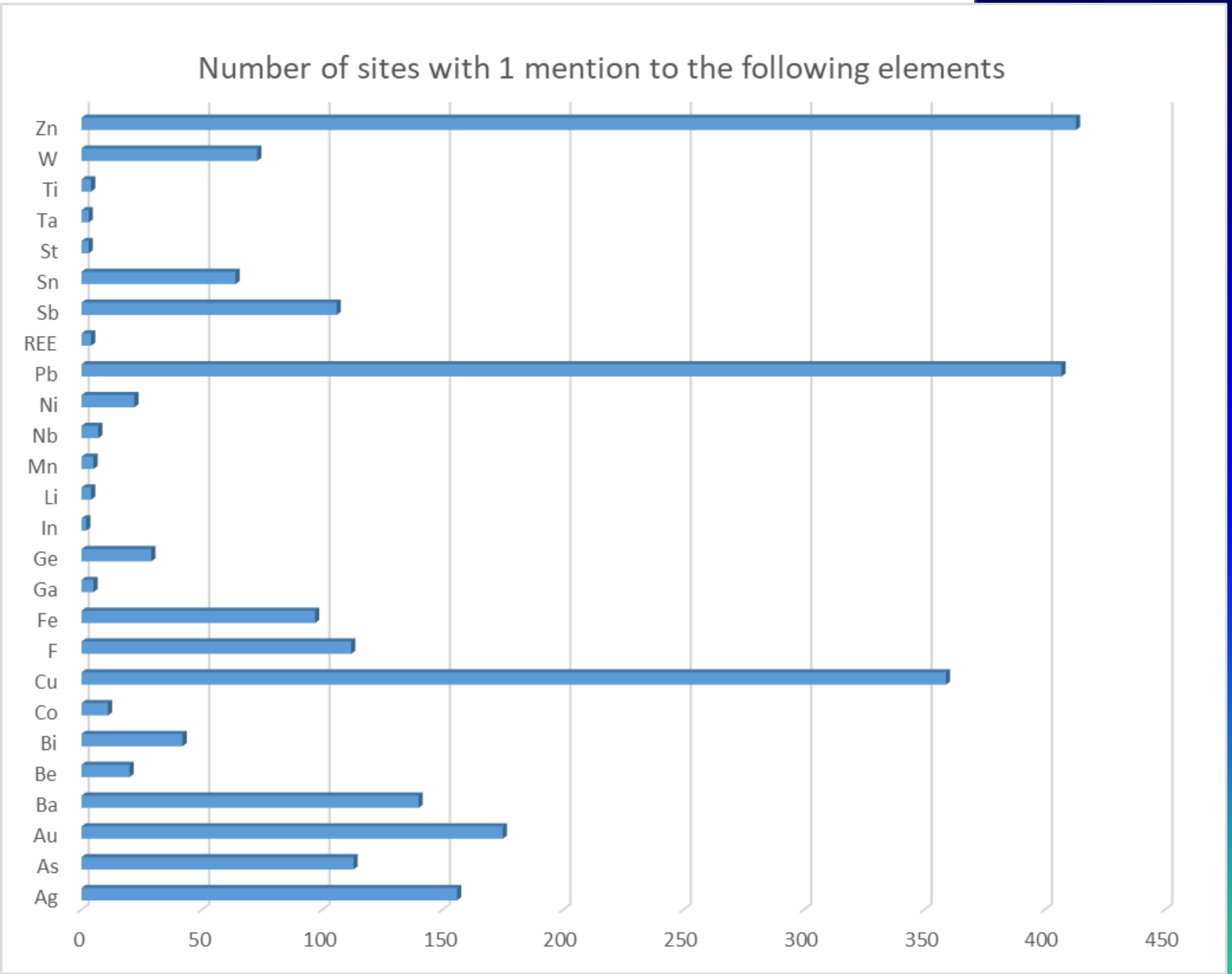
Anthropogenic concentration database. Based on previous projects ProMine/ProSUM results

- Commodities. Based on historical mining activity. An old Pb/Zn mine ➔ Pb/Zn in tailings
- 923 sites in France but only 12 with grade/content information



Anthropogenic resources

- Data represents the XXth century mining activity in France: Pb/Cu/Zn mines are overrepresented
- 1 site = 1 anthropogenic deposit
- 1 mine can hosts several sites
- Some CRMs >50 occurrences: Sb, W, F
- Other special/minor metals, not exploited by the past ➔ underrepresented?
- Few information about rock wastes



Sobering reality

- Often, historical mine sites presents a consequent environmental issue (soil pollution, acid drainage, geotechnical risks, etc.) but **the presence of valuable elements or CRM is low/very low**
- Data treatment task is ongoing, identify sites with metals content > threshold value
- Other factors should be considered: state of the site, level of risk, ecological rehabilitation ongoing…

Table 1. Rare element content in the most concentrated Zn samples (mg/kg DM)

Zn	964	1,287	1,985
Ga	7.1	3.3	4.4
Ge	1.8	1.6	1.9
In	<0.2	<0.2	<0.2
Ta	0.54	0.41	0.32
Tl	24	24.4	32.2

CRM content in Carnoulès tailing.
Bodenan et al. 2015

Challenges to assess CRM in tailings

- Old mining activity in France was **for XXth century metals needs**
- Few CRMs from 2023s EU list were exploited in France: Sb, W, Ge, bauxite, F
- >400 tailings of Pb/Zn mines in France. **What about the presence of connected substances such as Ge, In, Ga?** In many cases not measured.
- Understand the history of the mining exploitation and the geology of the ore ➔ predictivity tools
- Need to rebuild a **sample mining waste catalogue**, analyse it and enrich national inventory
- Mining waste inventory oriented for resources: first step to catch investors and re-explore mining wastes deposits

01.

The perfect case study?

Looking for a win-win case study?

- The ideal case study for a recovery project in mining wastes

Environmental problems to solve

Problems already solved

CRMs presence

Social acceptance

Towards a real metal recovery in mining wastes in France?

- Presently no industrial/mining projects focusing on metal recovery in mining wastes in France
- But the topic catch the attention in some **R&D projects**:
  - Horizon Europe: FutuRaM, EIS Exploration Information System, Tarantula (specific to W)
  - French R&D projects ANR: CMiO (Ge/In) and VARTA (W)
- Symbiosis between projects ➔ share data
- Pending questions about legal aspects

Next steps

- Feed the anthropogenic resources database with new data (metal content, volumes). Which accessibility for a such database?
- Data treatment & sample analysis!
- UNFC evaluation of any mining waste recovery project: presently **non viable projects**
- Develop recovery technologies and processes to recover CRM and treat pollution → ANR VARTA

FutuRaM

Future availability of secondary raw materials

Merci!

FutuRaM.eu

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Future availability of secondary raw materials

Mine waste in West Balkan area and mineral resource potential in Bor tailings

06.09.2023

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УНИВЕРЗИТЕТ У БЕОГРАДУ-РУДАРСКО-ГЕОЛОШКИ ФАКУЛТЕТ

Secondary raw materials (SRM)

In last decades, the SRM became extremely important potential source of Raw Materials. Particularly, it corresponds to the mining and metallurgical waste sites.

In many cases, **due to old technological processes only one or two minerals have been extracted from the polymetallic ore deposits** which contains still a high concentration of valuable secondary raw materials which are of high demand in modern society.

Our main purpose had been to acquire information about those **mining and metallurgic waste sites and evaluate their potential** in the area of **West Balkan**.

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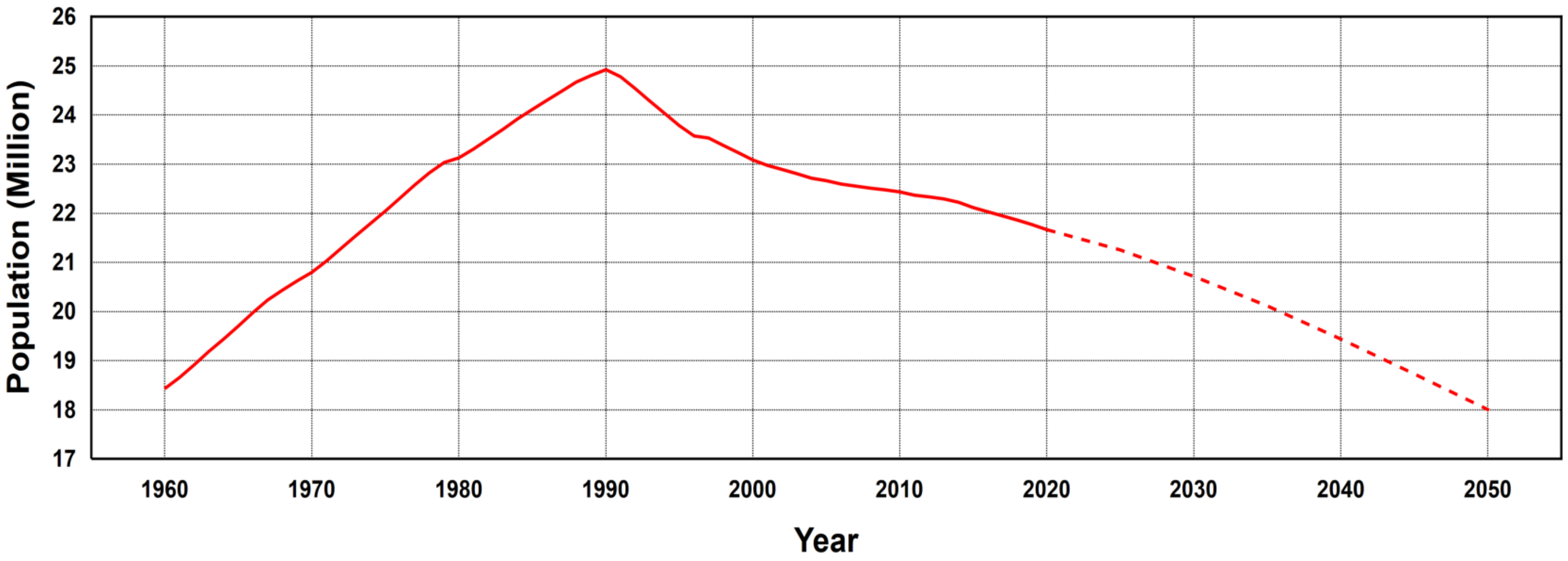
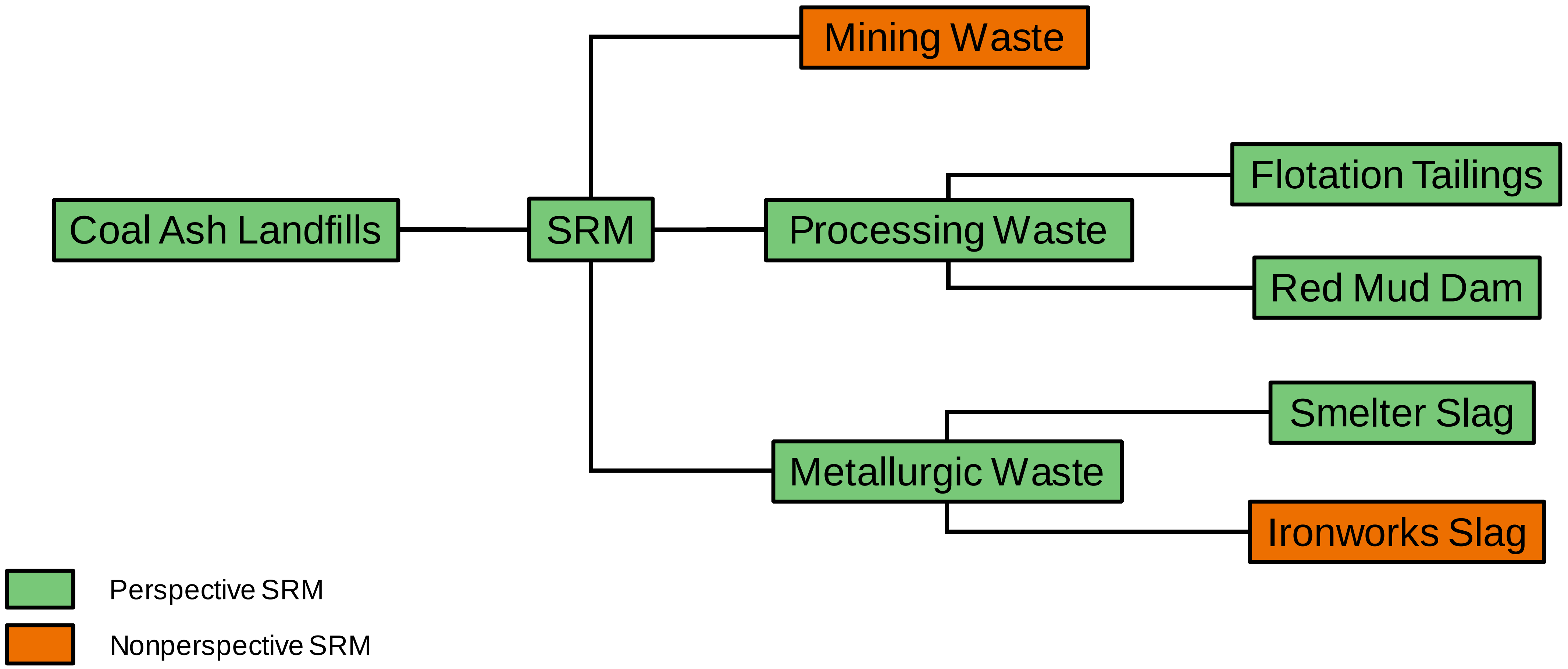
West Balkan (Basic data)

Country	Area (1000 km^2)	Population (million)	GINI	HDI	GDP	GDP (PPP)	GDP (nominal)
Albania	2.74	2.84	34.3	0.80	42,600	15,000	16,800
B&H	5.11	3.40	32.7	0.78	52,000	15,300	22,000
Croatia	5.60	4.04	28.3	0.85	117,900	29,200	63,200
Kosovo	<0.019	1.79	29.0	0.74	23,500	13,100	8,400
Montenegro	1.35	0.62	34.1	0.83	12,000	19,300	4,900
N. Macedonia	2.54	2.07	30.7	0.77	33,800	16,300	12,400
Serbia	7.75	6.90	33.3	0.81	130,600	18,900	52,000
W. Balkan	**26.18**	**21.67**	**31.8**	**0.80**	**58,900**	**18,200**	**25,700**



Classification dendrogram of secondary raw materials (SRM)



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Flotation tailings (Zletovo)

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Smelter Slag Landfill (Veles)

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Red mud Dam (Podgorica)

Coal Ash Landfill (Kostolac)

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SRM data collecting

The most common obstacles and problems were:

- inaccurate, unspecific, or unverified coordinates,
- data generalization and very general estimates,
- general lack of data.

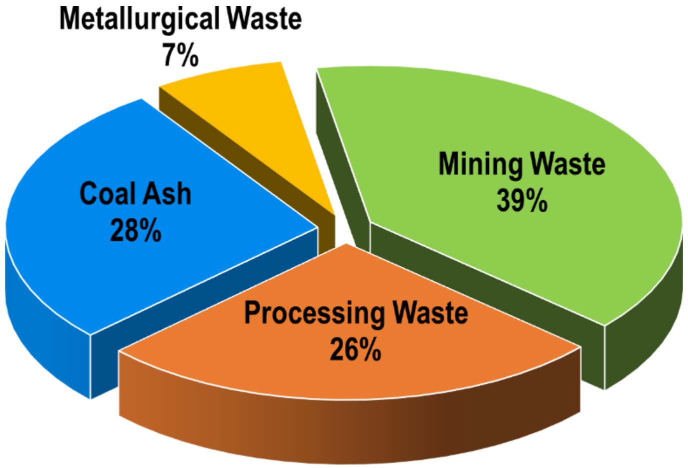
Very often, the one SRM landfill site is composed of several separate landfills, especially those that are still active, they are chemically very different from each other due to changes in technological processes in the past.

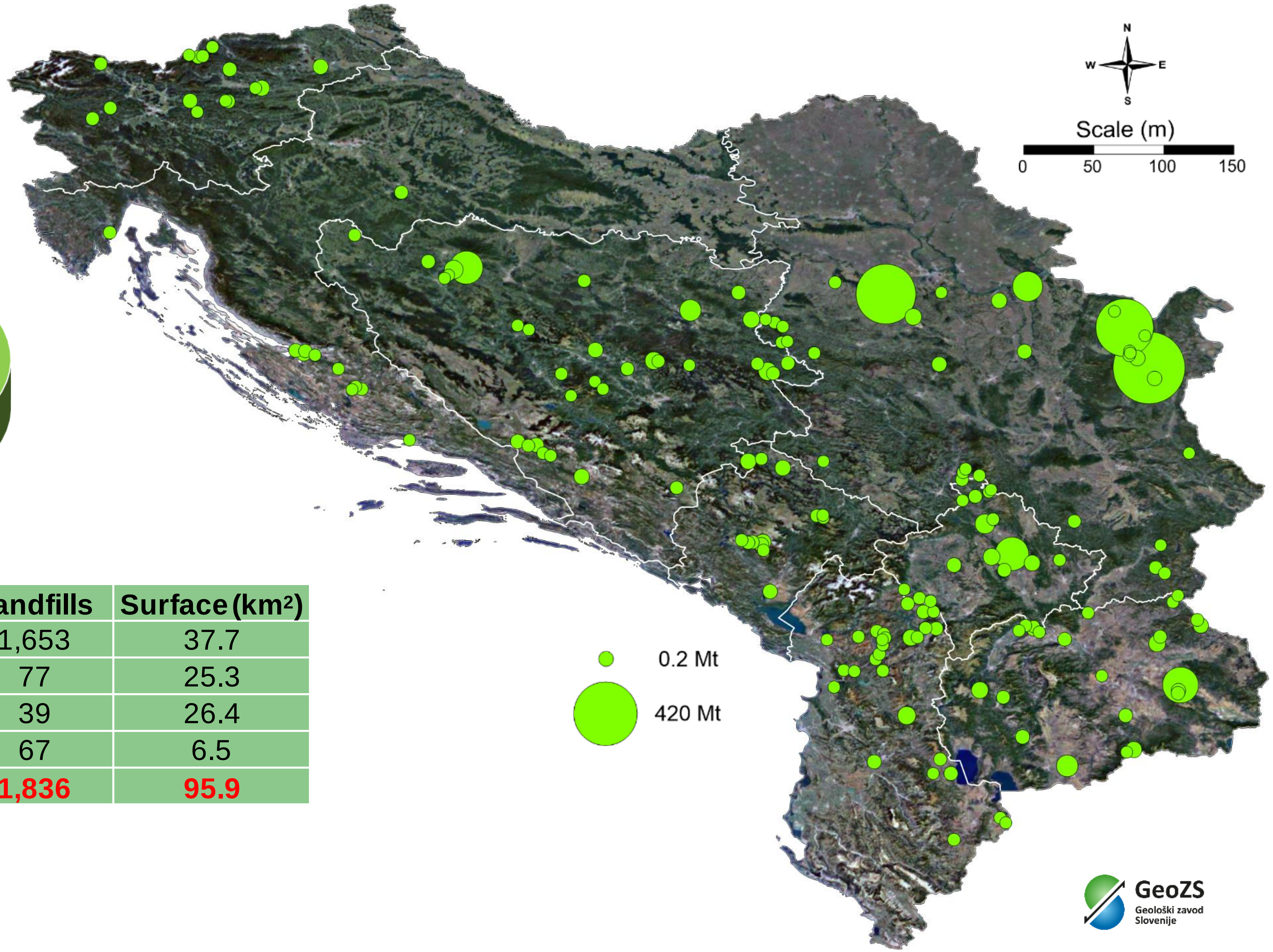
All collected data had been carried out using remote sensing methods in combination with existing open-source data bases and visual verification in Google Earth Historical Imagery

Open-source databases:
http://www.euromines.org/mining-europe/
http://www.europe-geology.eu/mineral-resources/
https://thediggings.com/
https://www.grida.no/
https://www.mindat.org/
https://www.usgs.gov/centers/nmic/

Spatial/geographical data:
https://land.copernicus.eu/pan-european/
https://www.google.com/earth/
https://www.openstreetmap.org/

SRM Deposits (West Balkan)





Type of Landfills	Location	Landfills	Surface (km²)
Mining Waste	120	1,653	37.7
Processing Waste	48	77	25.3
Metallurgic Waste	29	39	26.4
Coal Ash	24	67	6.5
West Balkan	**220**	**1,836**	**95.9**

c. 3,200 million tons

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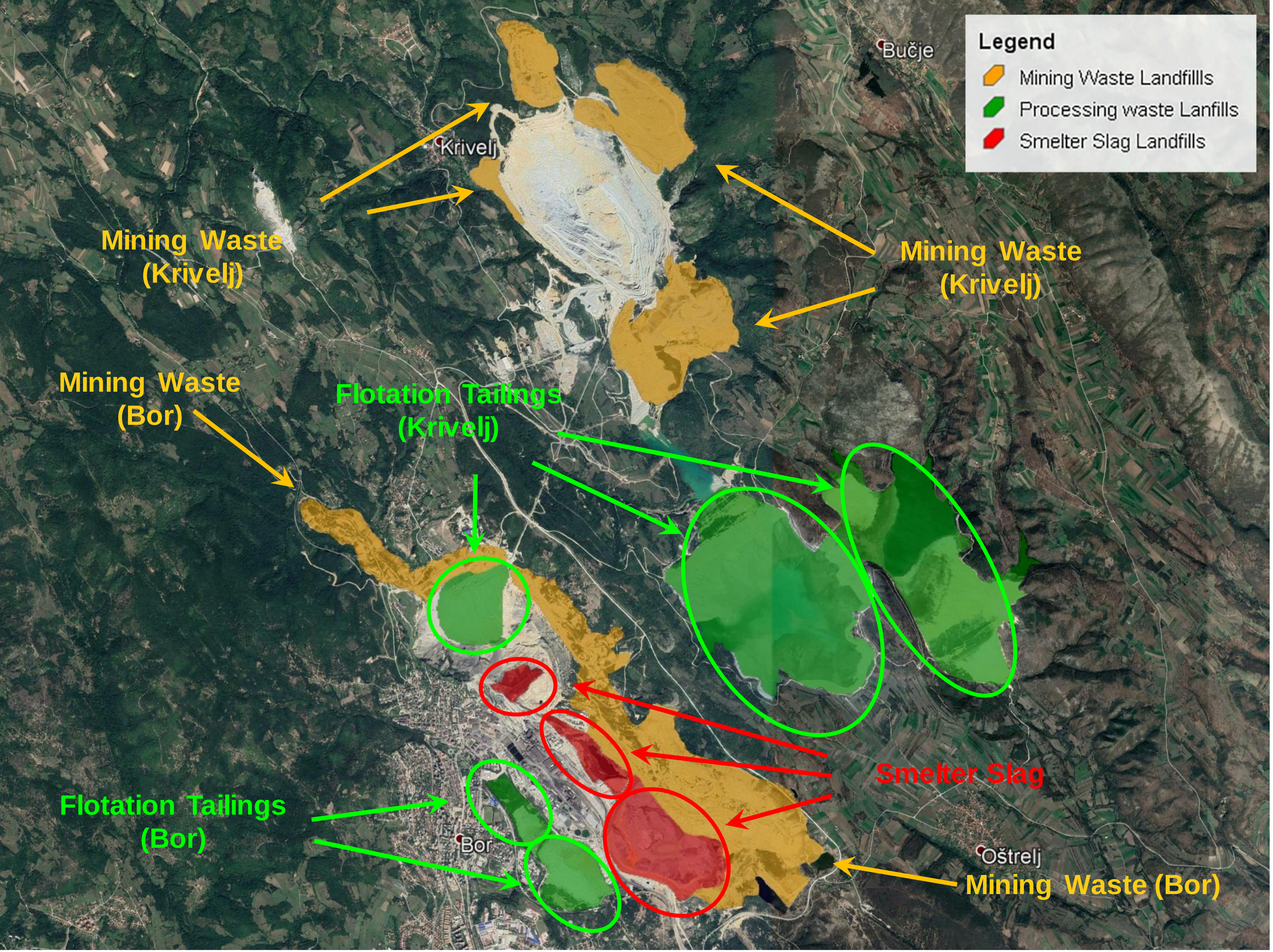

Bor/Krivelj
Cu open pit

One location
Fourteen Landfills

Mining waste : 6
Flotation tailings: 5
Smelter slags: 3

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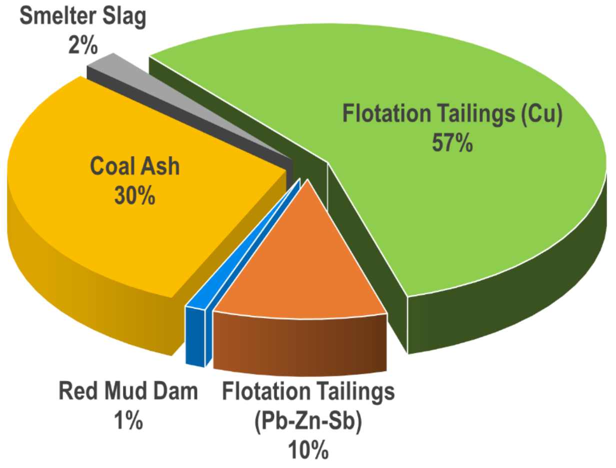
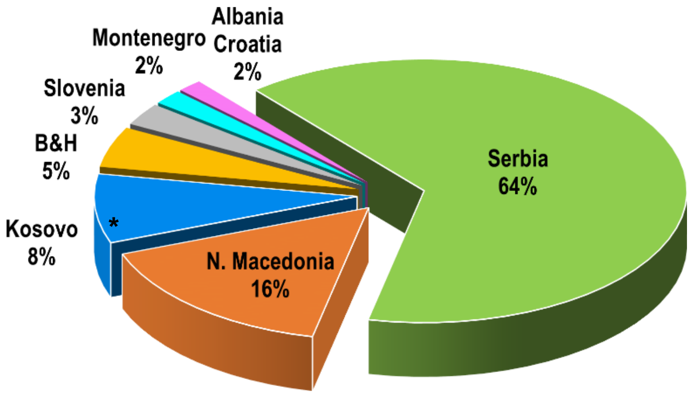
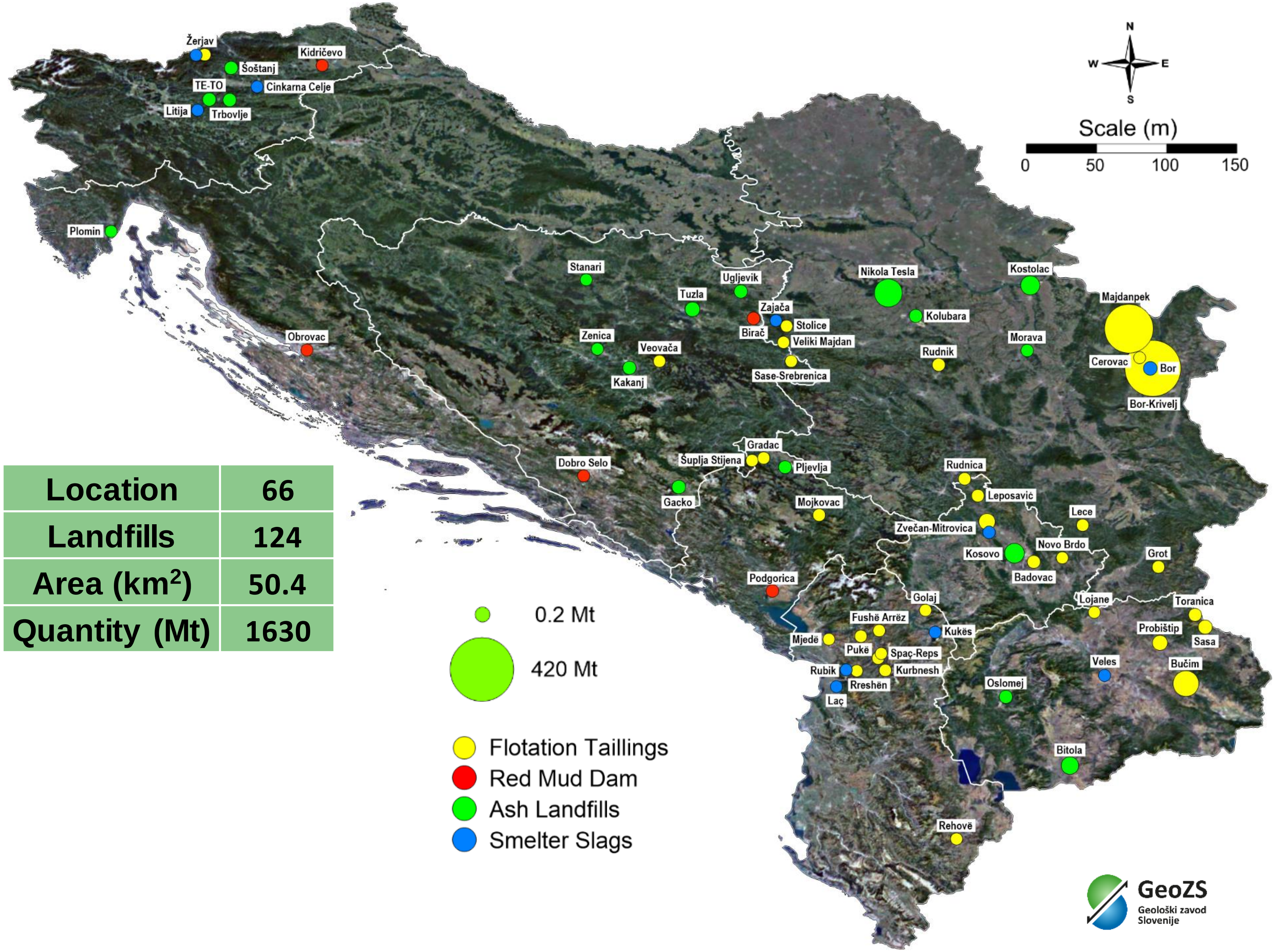
Perspective SRM Deposits (W. Balkan)





Location	66
Landfills	124
Area (km^2)	50.4
Quantity (Mt)	1630



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Trench Sampling

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Hand Drilling

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Composite samples/Chemical analyses

Type	Sample
Flotation Tailings (Cu)	8
Flotation Tailings (Pb-Zn-Sb)	29
Smelter Slag	6
Red Mud Dam	4
Coal Ash	16
West Balkan	**63**

ICP-MS/ES after Total 4-acid or Aqua regia digestion
(65 chemical elements)

Ag, Al, As, **Au**, B, Ba, Be, **Bi**, Ca, Cd, Co, Cr, Cs, **Cu**, Fe, **Ga**, Ge, Hf, Hg, **In**, K, Li, Mg, Mn, **Mo**, Na, Nb, Ni, P, **Pb**, Pd, Pt, Rb, **Re**, S, **Sb**, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, **W**, Zn, Zr
REE (Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sc, Sm, Tb, Tm, Y, Yb)

Selecting criteria

Ag > 10 g/t
Au > 0.1 g/t
Bi > 50 g/t
Cu > 0.1 %
Ga > 50 g/t
In > 10 g/t
Mo > 1,000 g/t
Pb > 0.5 %
Re > 0.1 g/t
Sb > 1,000 g/t
W > 100 g/t
Zn > 0.5 %

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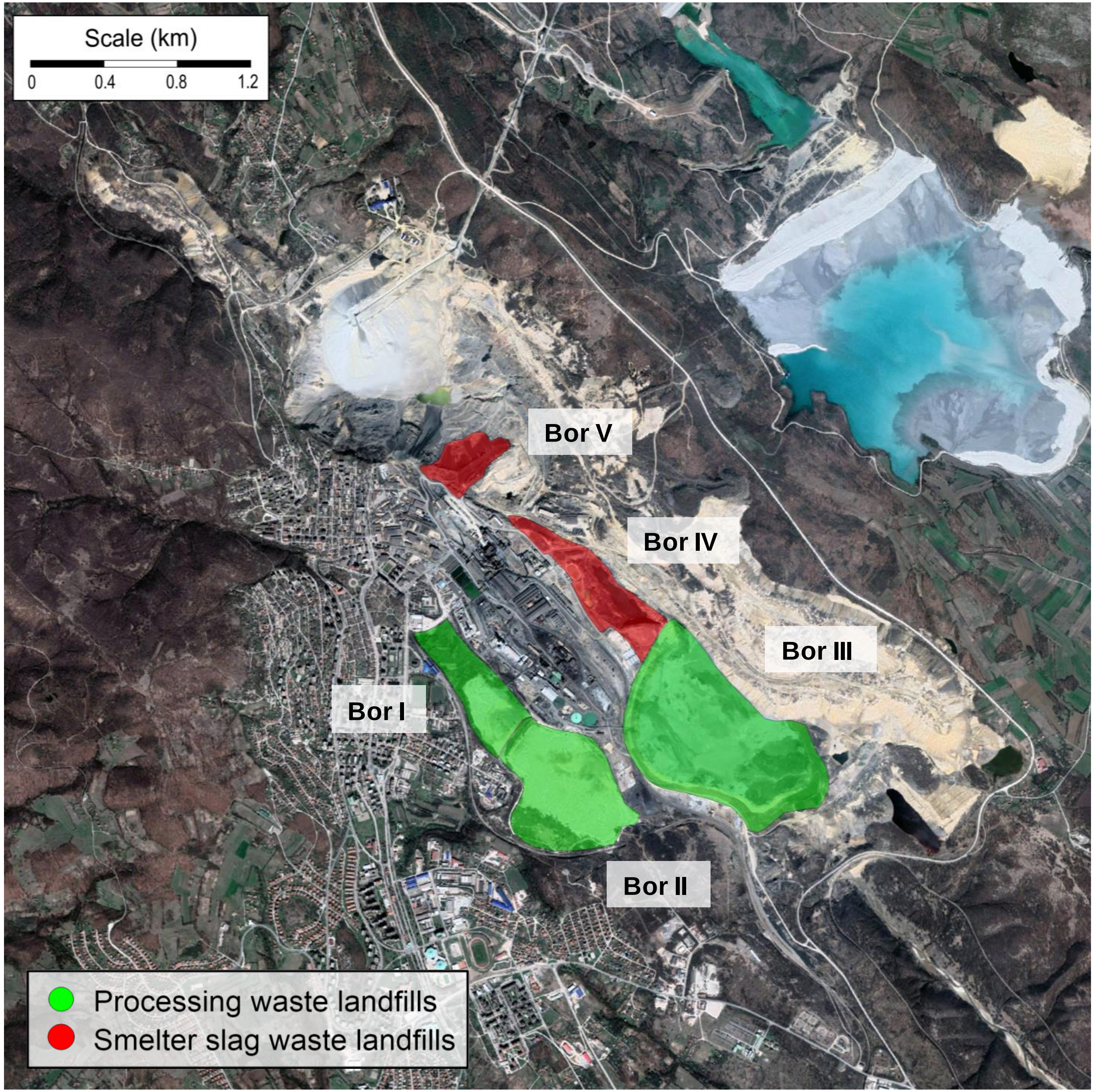
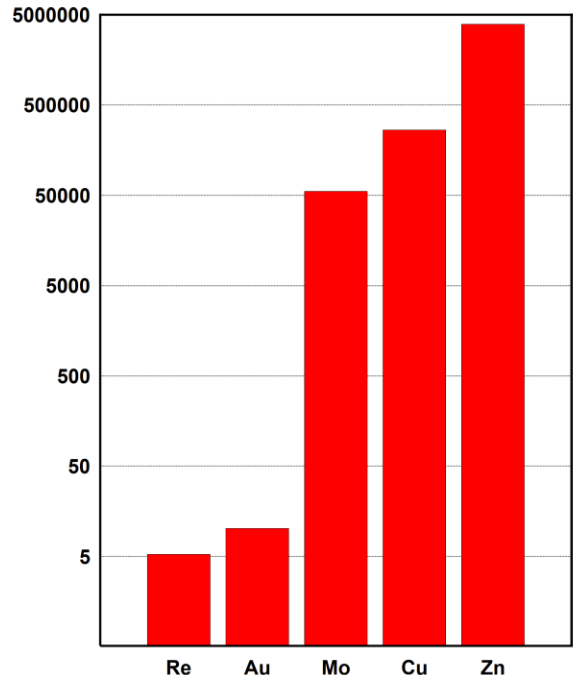
Bor mine





Element	Quantity (t)
Re	5.3
Au	10
Mo	55,000
Cu	260,000
Zn	390,000

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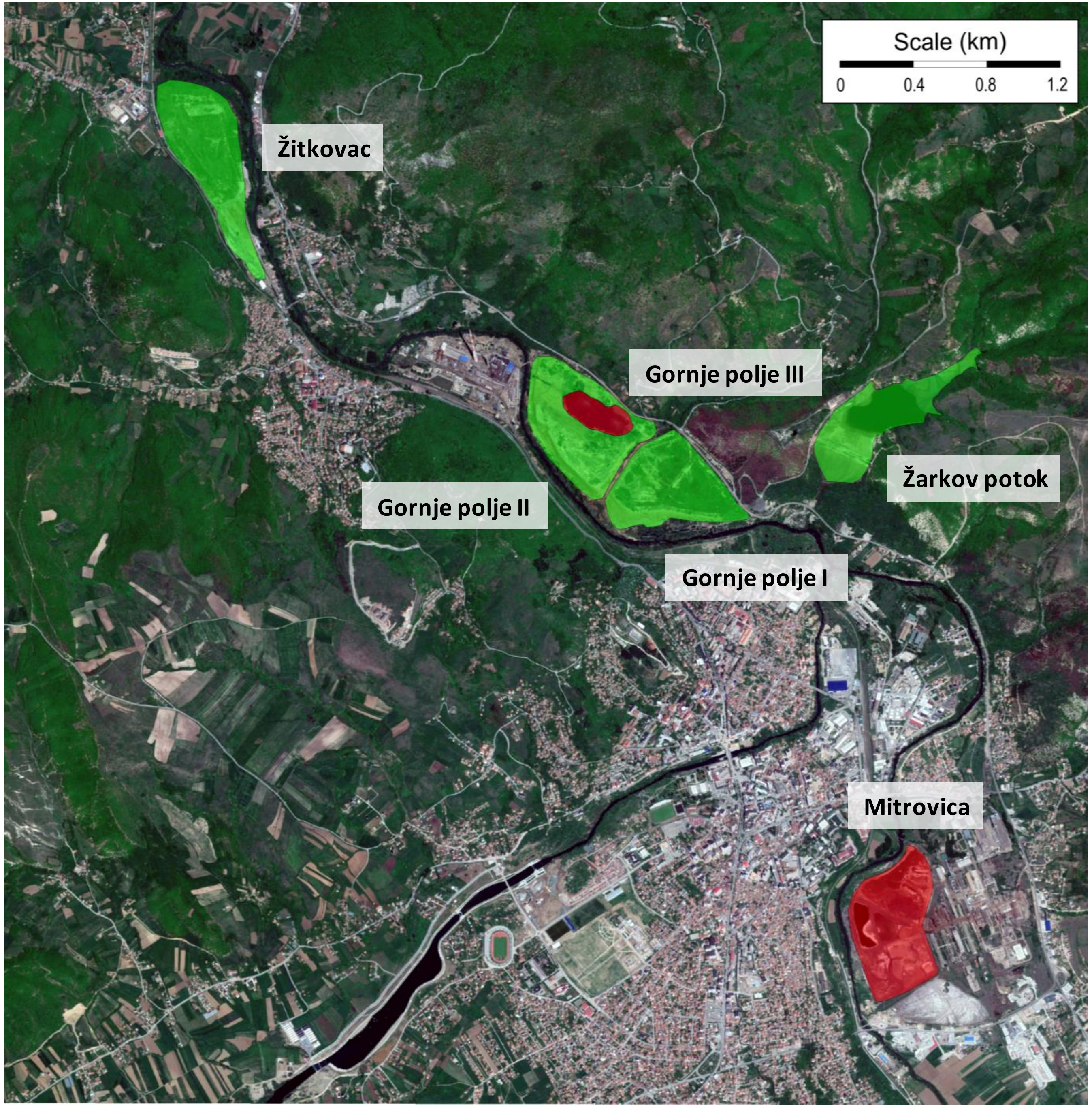
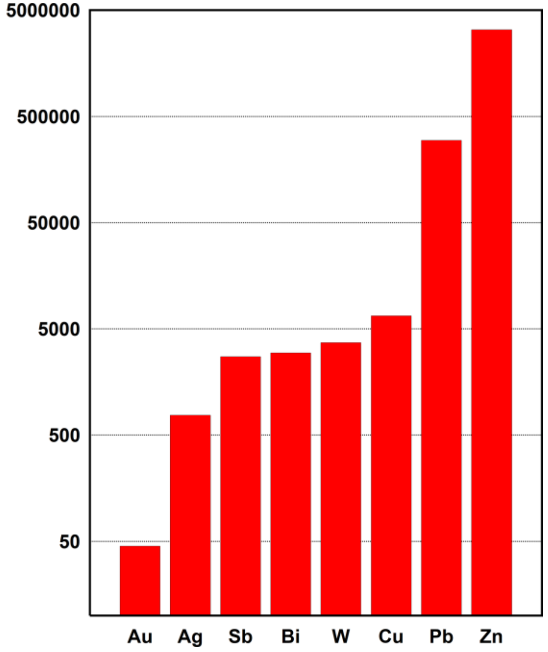
Trepča mine





Element	Quantity (t)
Au	45
Ag	770
Sb	2,700
Bi	3,000
W	3,700
Cu	6,700
Pb	300,000
Zn	330,000

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Metal rates and values according to the years

Element	Metal (t)	Rate (USD/kg)			Mil. USD*		
		2000	2020	2022	2000	2020	2022
Ag	1,500	192	463	884	289	698	1,330
Au	73	10,300	53,900	68,600	752	3,940	5,010
Bi	3,100	6.0	7.72	7.17	18	24	22
Cu	310,000	1.27	4.81	10.5	394	1,490	3,260
In	260	188	220	299	48	56	76
Mo	55,000	5.90	24.8	45.8	327	1,370	2,540
Pb	620,000	0.387	1.57	2.38	240	972	1,470
Re	5.3	1,110	1,030	3,550	6	5	19
Sb	15,000	1.50	5.87	12.8	23	90	196
W	3,700	8.20	30.3	49.3	30	113	183
Zn	970,000	1.08	1.91	4.10	1,040	1,840	3,950
SUM					**3,170**	**10,600**	**18,100**

Metal values per country (March 2022)

Element	Albania	B&H	N. Macedonia	Kosovo	Serbia
Ag	-	58	309	842	124
Au	168	-	85	3,830	934
Bi	-	-	-	22	-
Cu	201	-	132	70	2,850
In	-	-	62	-	14
Mo	-	-	-	-	2,540
Pb	-	-	514	856	104
Re	-	-	-	-	19
Sb	-	-	77	35	84
W	-	-	-	183	-
Zn	-	21	781	1,480	1,670
SUM*	**369**	**79**	**1,961**	**7,313**	**8,341**

*the rough estimation done without semi-industrial beneficiations and metal extraction test

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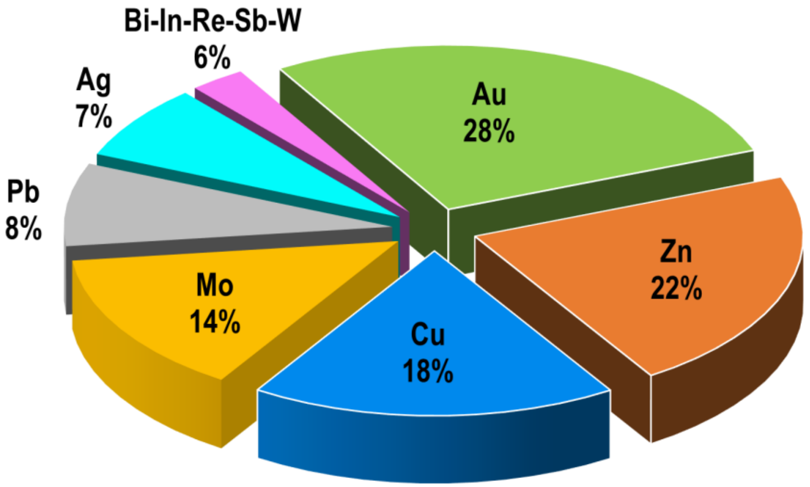
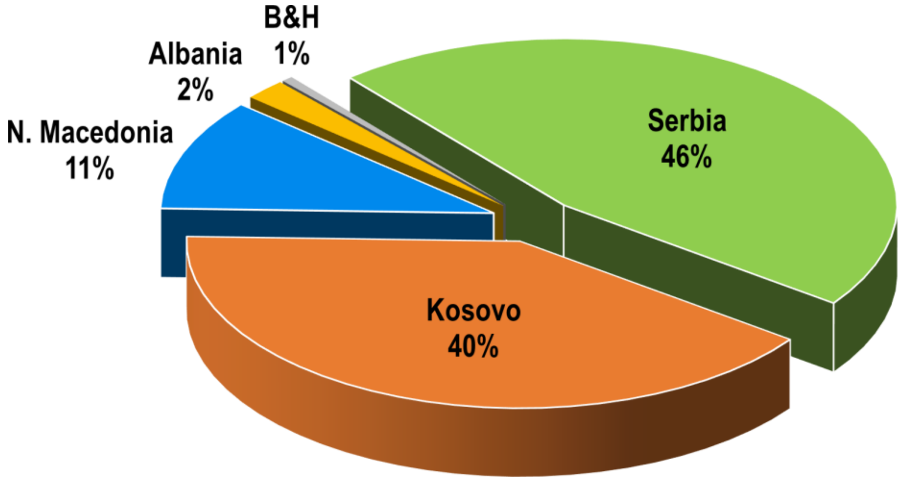
Estimated value of sulfide metals (West Balkan)

Element	Metal (t)	Metal Price (USD/kg)	Value (Mill. USD)*
Ag	1,500	884	1,330
Au	73	68,600	5,010
Bi	3,100	7.17	22
Cu	310,000	10.5	3,260
In	260	299	76
Mo	55,000	45.8	2,540
Pb	620,000	2.38	1,470
Re	5.3	3,550	19
Sb	15,000	12.8	196
W	3,700	49.3	183
Zn	970,000	4.10	3,950
West Balkan			**18,100**





*the rough estimation done without semi-industrial beneficiations and metal extraction test

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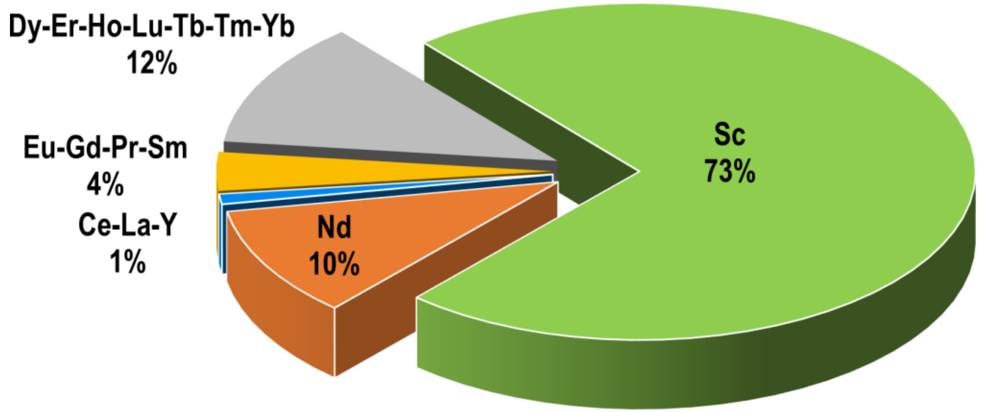
Estimated value of REE_2O_3 (West Balkan)

REE	Metal/Oxide Ratio	Oxide Price (USD/kg)	REE (Kt)	Value* (Mill. USD)
Sc	1.53	904	18	24,550
Y	1.27	7.6	23	220
La	1.17	1.0	31	34
Ce	1.17	1.0	62	71
Pr	1.17	100	7.3	850
Nd	1.17	110	28	3,590
Sm	1.16	2.2	5.7	14
Eu	1.16	28	1.4	44
Gd	1.15	62	4.9	348
Tb	1.15	1,990	0.7	1,540
Dy	1.15	356	4.5	1,820
Ho	1.15	131	0.9	136
Er	1.14	42	2.6	125
Tm	1.14	150	0.4	63
Yb	1.14	14	2.5	38
Lu	1.14	839	0.4	342
West Balkan			192	33,800



REE_2O_3	33,800	Mill. USD
Sulfide Metal	18,100	Mill. USD
Total Potential	51,900	Mill. USD

*the rough estimation done without semi-industrial beneficiations and metal extraction test

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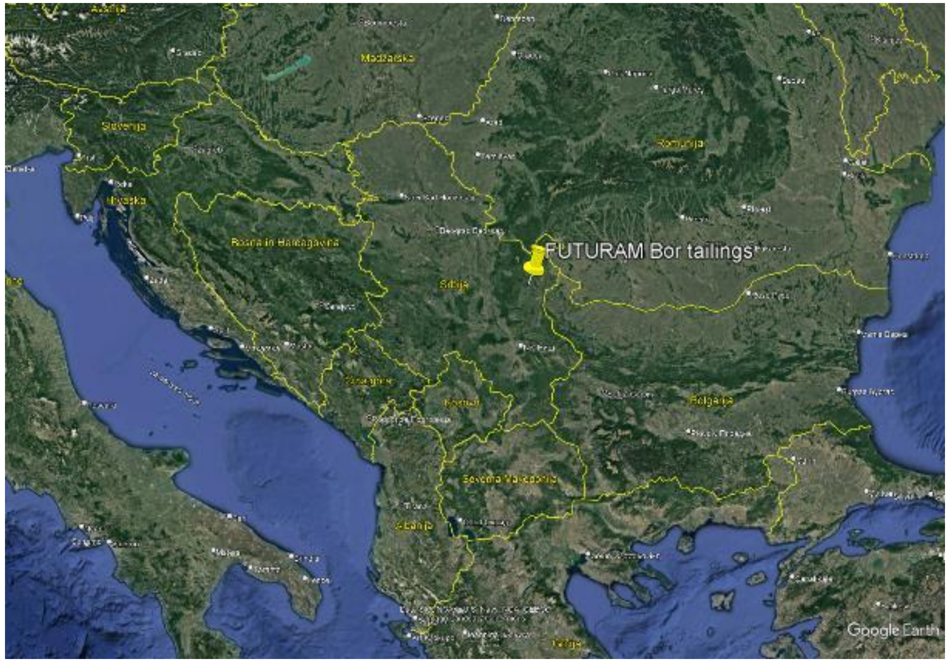
The FUTURAM - Bor case study

- To evaluate secondary raw material deposit (mine waste - tailings) according to UNFC classification
- To get experiences and record lessons learnt
- To suggest improvements and identify gaps for the use of UNFC classification for secondary raw materials



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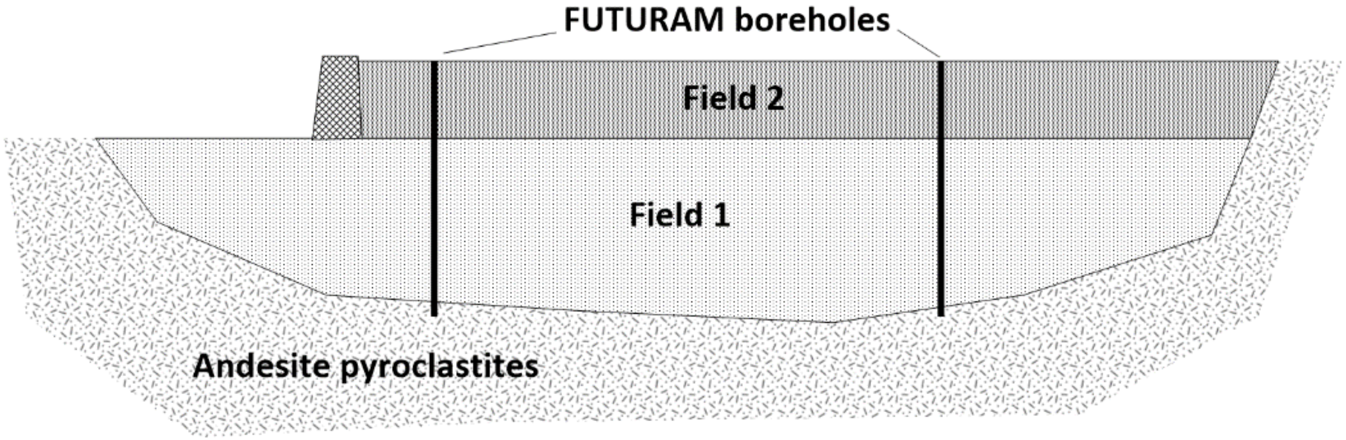
The FUTURAM - Bor case study

- Flotation tailings from Cu-Au mining (still containing Cu, Au, Ag + potentially Ga, Sn, Mo, REE and other elements)
- 2 fields:
  - Field 1 (below) in use from 1933 - approx. the end of 2nd WW (approx. 1 Mm^3)
  - Field 2 (upper part) in use after the 2nd WW until 1980 (approx. 2 Mm^3)
- These are the richest tailings in the area, because in that time, the high-grade ore was extracted and processed by the old processing technologies



Schematic cross section of tailings NW-SE, not in scale

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The FUTURAM Bor case study - work done

- overview of existing data ("Japanese" boreholes, RIS-Cure project), defining exploration works, arranging paperworks, public procurement etc.
- drilling of 2 boreholes through both fields until bedrock was reached (51.0 m + 65.0 m)
- core logging, preparing composite sample (every meter)
- air drying, crushing, homogenisation, size reduction (coning & quartering), archiving
- collecting samples from the past drillings from archive

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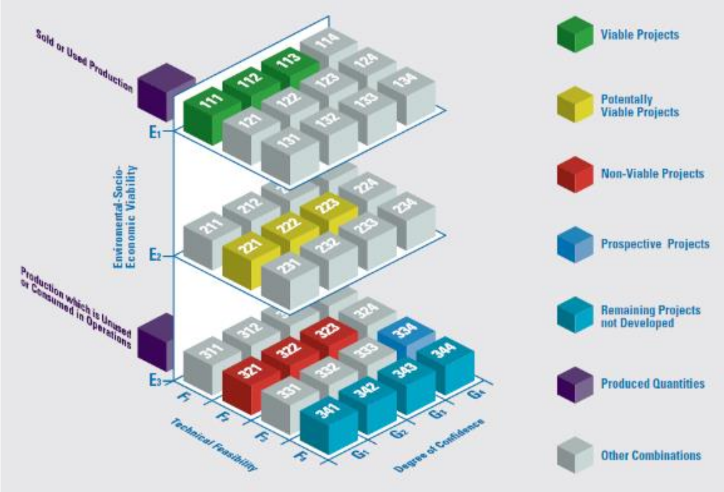
The FUTURAM Bor case study - work to be done

- Elemental determination (ACME labs, multiacid ultratrace) for FUTURAM samples and set of archive samples
- Potentially semi-industrial beneficiation and metal extraction tests (TBC)
- Conducting stakeholders surveys and legislation analysis (defining E axis)
- Resources and reserves estimation using UNFC methodology
- Reporting to FUTURAM and to IRM Bor institute (manager of the tailings)



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Thank you!

Secondary mineral resources in Finland and the Otanmäki tailings case site

September 6, 2023

T. Karlsson, J. Hokka, M. Kinnunen

Geological Survey of Finland GTK

FutuRaM
Future availability of secondary raw materials

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Extractive waste in Finland

Finland's extractive waste: 100 Mt annually, 74% of total waste streams

1,113 Mt waste rock mined since 16th century, 96% from 1969-2021, half in last decade

Over 500 Mt tailings generated since flotation's introduction in 1911

GTK

Extractive waste as secondary resource in Finland

>1000 closed and active mines in Finland, mostly closed and very small

Some interesting closed larger tailings sites (GTK database):

Concentrations mostly very uncertain!

Resource potential of closed extractive waste sites understudied!

Mine	Main commodity	Tailings (Mt)	Active	Some CRMs remaining (g/t)
Hitura	Ni, Cu	13.5	1970-2013	Ni 2140, Cu 980
Outokumpu/ Keretti	Cu, Zn, Au, Ag	9.5	1910-1989	Cu 1430, Co 600
Kotalahti	Cu, Ni	9.4	1959-1987	Mn 1100. Ni 610, Cu 330
Mustavaara	Fe, Ti, V	11.5	1975-1985	Mg 11900, Ti 2440, Cu 770, Mn 490, V 520
Otanmäki	Fe, Ti, V	11.8	1953-1985	Ti 47000, V 680
Pyhäsalmi	Cu, Zn	10	1962-2019	Cu 600, Baryte 50000
Vihanti	Zn, Cu, Pb	13.7	1954-1992	Cu 800
Vuonos	Cu, Co, Ni, Zn	9	1967-1986	Cu 1900, Ni 1000, Co 700, Mn 400
Aijala	Cu, Zn, Ag	2	1949-1974	Cu 1200
Orijärvi	Cu, Zn, Pb	1	1700s-1958	Cu 2000
Korsnäs	Pb	0.8	1961-1972	P 8000, La 7000, Eu 57

GTK

Extractive waste as secondary resource in Finland

Currently some tens of active mines in Finland (Au, Ag, Pb, Zn, Ni, Cu, PGE, Cr, S, Li, carbonates, talc, apatite, feldspar, soapstone) + several smaller quarries

Some examples of active mines with large (>10 Mt) tailings facilities and interesting CRMs:

Kemi Cr mine: Ni
Siilinjärvi apatite (P) mine: REE
Kevitsa Ni-Cu-PGE mine: Cu, Ni, V, Mg

GTK

Extractive waste as secondary resource in Finland

Low utilization of extractive waste as secondary resources, especially in metal mines

Mainly used for earth construction & cavity filling

Higher utilization in limestone quarries, e.g., Nordkalk utilized 95% of extracted material in 2021

Extractive waste as secondary resource in Finland

Lack of systematic national resource management hinders extractive waste utilization

Requires characterization considering resource quantities, technical viability, environmental & socio-economic issues

Existing data scattered (deposit data, risk assessments, compliance monitoring by authorities)

Secondary raw materials to be included in GTK's Mineral Database → FutuRaM database

GTK

Extractive waste as secondary resource in Finland

Value chains to support the use of side streams are lacking in the mining industry

Even though the technical use would be possible,the logistical costs or environmental impacts might be high

Source: Kinnunen P, Karhu M, Yli-Rantala E, Kivikytö-Reponen P, Mäkinen J (2022). A review of circular economy strategies for min tailings. *Cleaner Engineering and Technology* 8 (100499)

The Otanmäki mine

Fe-V mine owned first by Otanmäki Oy and later by Rautaruukki Oy

Active 1953-1985, during which 33.1 Mt of rock material was extracted

25.5 Mt of ore, 11.8 Mt of tailings (includes also some slags)

Current plans to utilize tailings and re-open the mine by Otanmäki Mine Oy

Photo: Valokuvausliike Hynninen

GTK

The Otanmäki ilmenite project

100% owned by Otanmäki Mine Oy,
see: https://www.otanmaki.fi/ilmeniittihanke/

The Otanmäki Mine Oy started the investigations at the Otanmäki tailings site in 2017

The current interim resource estimate indicate 9.8 Mt @ 7.9 % TiO_2 (16 % $FeTiO_3$)

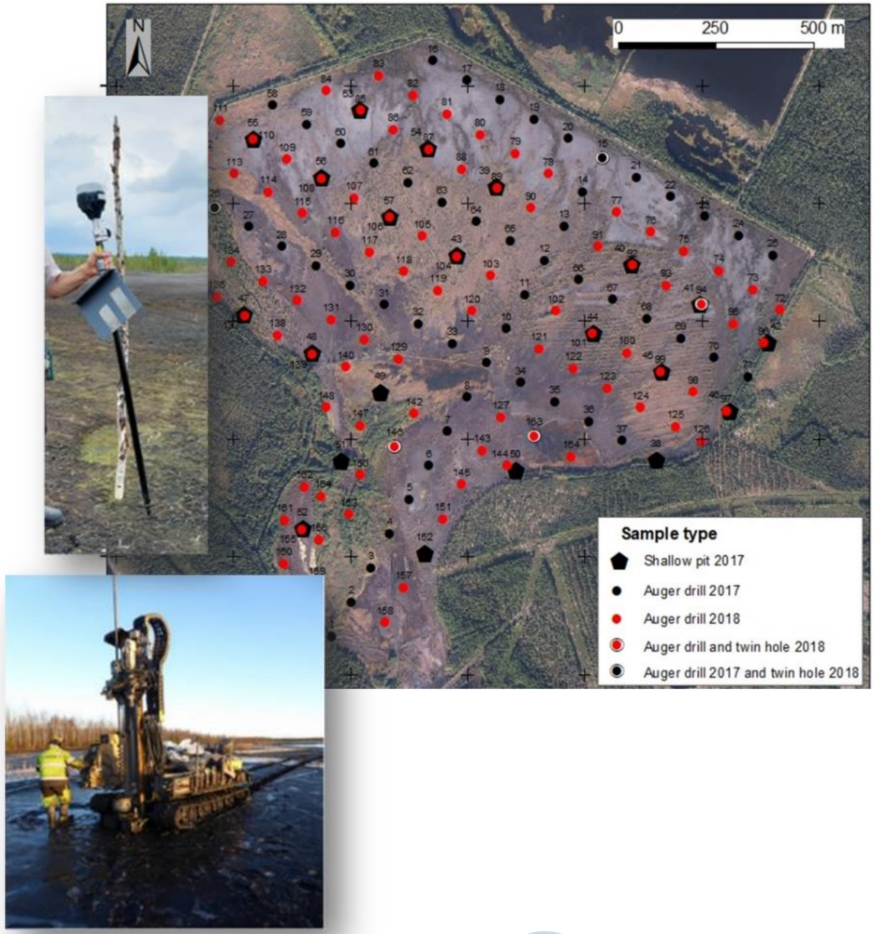
The company is currently completing its Prefeasibility Study and EIA and the plan is to start producing ilmenite by the year 2025

The Otanmäki ilmenite project

Investigations: systematic drilling & sampling, resource modeling, pilot-scale beneficiation tests at GTK Mintec

Otanmäki ilmenite resource classified as E2F2G2 (potentially viable) per the United Nations Framework Classification for Resources (UNFC)

Otanmäki tailings facility as FutuRaM case site & future utilization example



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FutuRaM project and the resource management of extractive waste

Concrete FutuRaM actions at Otanmäki:

- Testing and comparing 3 different drilling/sampling methods (auger, split & spoon, tube)
- Are there significant differences between the methods?
- What is the reliability of the sampling already done at the site?

GTK

FutuRaM project and the resource management of extractive waste

Concrete FutuRaM actions at Otanmäki:

- Investigate and model in detail a small part of the tailings area
  - 45-50 closely spaced drill cores
- Assessing the reliability of the resource estimation done based on more scattered drilling

GTK

FutuRaM project and the resource management of extractive waste

Concrete FutuRaM actions at Otanmäki:

- Document how the investigations and UNFC classification was made as an example for future projects

FutuRaM

Future availability of secondary raw materials

Thank you!

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