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1 **A colour code as a tool to raise public awareness of lithium resources**

2
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8 9 **Preface**

10 The supply of lithium to industry and its impact on the environment is a matter of growing
11 public concern. Here, we propose a simple colour code to capture the diversity and
12 characteristics of lithium resources in order to raise public awareness.

13 14 **A common tool for public debate**

15 Colour codes are used, for example, to refer to different water and hydrogen resources and
16 carbon sinks (Rost et al., 2008; Macreadie et al., 2021; Osselin et al., 2022). These colour codes
17 have different uses in the scientific community, and are essentially a practical tool for
18 categorising, communicating and disseminating knowledge to the public.

19 The global development of electric vehicles powered by Li-ion batteries will put
20 considerable pressure on raw material resources, including lithium, for decades to come
21 (Bibienne et al., 2020; Habib et al., 2020; Maisel et al., 2023; Balaram et al., 2024; Lawley et
22 al., 2024). As with many other metals, the extraction of lithium is the subject of intense debate.
23 Indeed, its impact on the environment sometimes appear to be at odds with the ecological
24 transition of which it is considered one of the pillars (Kaunda 2020; Lèbre et al., 2020; Sonter
25 et al., 2023). In this context, it is important to find ways of developing public awareness and
26 facilitating the communication between stakeholders in the public debate (citizens, scientists,
27 companies, media, policy-makers, NGOs etc.).

28 Here, we propose a simple colour code for the main types of lithium resources. As far
29 as possible, the colours assigned to the different lithium resources reflect the environment in
30 which they are found. Combined with non-technical keywords, the colours are a simple
31 mnemonic to help capture the specific characteristics and highlight the diversity of lithium
32 resources (Fig. 1). Along with the colour code, we provide a brief overview of their origin,
33 geographical distribution, environmental impact and rank in current global production. By

34 using this colour code, the stakeholders in the public debate would share a simple common
35 lexicon and basic knowledge, without having to master all the technical vocabulary when
36 discussing the issues at stake.

37

38 **"White" lithium**

39 "White" lithium is dissolved (up to several thousand mg/L) in the water beneath salt lakes (also
40 referred to as "salars"). "White" here refers to the colour of the salt and salt lake landscapes.
41 "White" lithium has accounted for >30% of the lithium mined worldwide in 2022-2023 ([USGS,](#)
42 [2024](#)). However, "white" lithium is predominantly found in two major geographical areas
43 (Argentina-Chile-Bolivia and China), often at a distance from the many battery factories being
44 developed around the world ([Bowell et al., 2021](#)). Technologies for extracting lithium from
45 aqueous solutions are developing rapidly, and processes that no longer require the lithium to be
46 concentrated by evaporation over large surfaces will become widespread (i.e. "direct lithium
47 extraction" or DLE). However, the extraction of "white" lithium puts critical pressure on land
48 use and water resources for the populations living around the salars, which are subjected to a
49 very arid climate ([Vera et al., 2023](#); [Halkes et al., 2024](#); [Mousavinezhad et al., 2024](#)). It is
50 estimated that the production of one tonne of lithium carbonate equivalent using solar
51 evaporation process results in the emission of 3 to 4 tonnes of CO₂ equivalent and a freshwater
52 consumption for the process of 25 to 56 m³ ([Kelly et al., 2021](#); [Mas-Fons et al., 2024](#)), not
53 including the water evaporated during the solar evaporation process (100-300 m³)
54 ([Mousavinezhad et al., 2024](#)). DLE requires industrial operations for extraction, purification,
55 and conversion that emit the equivalent of 20 tonnes of CO₂ and consume 20 to 150 m³ of water
56 to produce one tonne of lithium carbonate equivalent, although fresh water can be recovered
57 through the processing of Li-rich brines ([Baspineiro et al., 2020](#); [Mousavinezhad et al., 2024](#)).
58 Energy consumption is variable, as most processes plan to generate the required electricity on-
59 site using photovoltaic panels due to the high levels of sunlight in the regions concerned.

60

61 **"Grey" lithium**

62 This is lithium extracted from rocks in conventional open pit or underground mines. By
63 extension, "grey" lithium could also refer to lithium extracted from mining and processing
64 residues ([Bradley et al., 2017](#); [Chernoburova & Chagnes, 2023](#)). "Grey" here refers to the light
65 hue of most lithium-enriched ores (e.g. pegmatites, granites, clays), which typically contain
66 around 0.6-1.1 wt% Li ([Bowell et al., 2021](#)). "Grey" lithium has accounted for >55% of the
67 lithium mined worldwide in 2022-2023 ([USGS, 2024](#)). Unlike white lithium, grey lithium

68 resources are found in varying amounts on all continents, although current production is limited
69 to a few countries (mainly Australia) (Bowell et al., 2021; USGS, 2024). This means that the
70 "grey" lithium mines could be relatively close to the battery factories, allowing producing
71 countries to have a better control on the value chain. However, the quantities of water and
72 energy required to extract "grey" lithium from lithium-enriched pegmatites can be very large,
73 due to the mining, milling and refining operations. It is estimated that the production of one
74 tonne of lithium carbonate emits the equivalent of 15-22 tonnes of CO₂ and consumes 77 m³ of
75 water (Kelly et al., 2021; Mas-Fons et al., 2024). Furthermore, the preservation of water
76 resources, landscapes, ecosystems, and the management of mining wastes are additional
77 challenges for the social acceptance and further development of "grey" lithium (Kaunda 2020;
78 Lèbre et al., 2020; Sonter et al., 2023).

79

80 **"Pink" lithium**

81 "Pink" lithium comes from recycling, mainly from Li-ion batteries used in electric vehicles.
82 Despite significant R&D and regulatory efforts in eco-design, life cycle assessment and battery
83 recycling routes, current production of "pink" lithium is still very limited (Swain, 2017;
84 Neumann et al., 2022; Ali et al., 2024; Zhou et al., 2024a). Various scenarios suggest that "pink"
85 lithium has the potential to supply about 10-60% of the raw material demand for Li-ion batteries
86 by 2035-2040 (Qiao et al., 2021; Maisel et al., 2023; Zhou et al., 2024b). Therefore, even in the
87 most optimistic scenarios, sustained primary lithium production will still be required. While the
88 main advantage of recycling is that it preserves part of the resource, it should also be
89 remembered that recycling is an energy-intensive process that also requires the use of many
90 chemicals. However, it is currently difficult to estimate the amount of CO₂ emissions, energy
91 consumption, and water consumption per tonne of lithium carbonate produced by Li-ion battery
92 recycling processes that will be industrialised in the coming years (Chagnes & Forsberg, 2023;
93 Zanoletti et al., 2024). This is because many hydrometallurgical and pyrometallurgical
94 recycling routes are conceivable, and the chemistry of Li-ion batteries is very diverse.
95 Furthermore, the recycling of Li-ion batteries does not only lead to the production of lithium
96 carbonate or lithium hydroxide but also to the production of other metal salts (Ni, Co and Mn
97 sulphates) prior to the production of lithium carbonate/hydroxide, which contribute to the
98 environmental impact of the process.

99

100

101

102 **"Black" lithium**

103 This is lithium dissolved (up to a few hundred mg/L) in deep, non-potable waters that occur
104 naturally in hydrocarbon reservoirs. "Black" here refers to the colour traditionally associated
105 with oil ("black gold"). "Black" lithium could therefore be extracted from these groundwaters
106 by DLE, with or without co-extraction of hydrocarbons. Recent studies have highlighted
107 resources of comparable size to "white" and "grey" lithium (Kumar et al., 2019; Dugamin et
108 al., 2021, 2023; Mackey et al., 2024). "Black" lithium production could benefit from the
109 infrastructure and investment capacity of oil and gas companies, and could develop strongly in
110 the near future. By extension, "black" lithium could also refer to lithium that could be extracted
111 from coal fly ash (Qin et al., 2015; Talan and Huang, 2022). The paradox of extracting both
112 hydrocarbons/coal and lithium for use in electric vehicles, which are expected to replace
113 internal combustion vehicles, is striking. A potentially more environmentally friendly way to
114 extract "black" lithium could be to co-produce low-enthalpy geothermal energy (like "yellow"
115 lithium, see below), or to recover "black" lithium during carbon capture, utilisation and storage
116 operations. Several "black" lithium projects are currently under development around the world
117 (Knapik et al., 2023).

118

119 **"Yellow" lithium**

120 "Yellow" lithium is that which is dissolved (up to a few hundred mg/L) in warm water used for
121 geothermal energy. "Yellow" here refers to the landscape of one of the world's most famous
122 geothermal areas (Yellowstone, USA). Potential resources are substantial and well distributed
123 around the world (Sanjuan et al., 2022; Gourcerol et al., 2024). Production of "yellow" lithium
124 hasn't yet reached the large-scale industrial stage, although several projects are being
125 developed, for example in the Rhine Graben (France, Germany) (Sanjuan et al., 2022; Dugamin
126 et al., 2024) and the Salton Sea (California) (Dobson et al., 2023). The principle of combining
127 low-carbon geothermal energy with DLE may seem attractive from an environmental and
128 economic perspective (Schenker et al., 2024; Weinand et al., 2023). However, control of
129 induced seismicity and groundwater quality during geothermal operations will be key to social
130 acceptance of "yellow" lithium (Renoth et al., 2023).

131

132 **"Blue" lithium**

133 "Blue" lithium refers to lithium dissolved in ocean and seawater, whose average concentration
134 is 0.1-0.2 mg/L. Seawater would represent a tremendous reservoir of lithium (ca. 230 billion
135 tons) (Yang et al., 2018). However, combined with the abundance of interfering ions (e.g.,

136 magnesium), the extraction of "blue" lithium at such low concentrations is technically and
137 economically highly challenging. This is especially true because no selective materials exist
138 today to recover lithium from seawater, and the low concentration of lithium in seawater implies
139 that an energy-intensive process is needed to extract and concentrate the lithium (Li et al., 2021;
140 Mends and Chu 2023). Alternatively, "blue" lithium could be recovered from the Dead Sea and
141 seawater desalination waste brines (Alsabbagh et al., 2021; Zhang et al., 2021; Lee et al.,
142 2023). At present, there is no operational plan for industrial extraction of "blue" lithium.

143

144 **Concluding remarks**

145 Resource inventories, extraction and recycling technologies, environmental impacts and
146 regulations are evolving very rapidly so the background information provided here will be
147 subject to significant change in the near future. Although a generic colour code may facilitate
148 communication and awareness in the public debate, it remains essential to consider the pros and
149 cons of each mining or recycling project on a case-by-case basis. Given that any industrial
150 extraction or recycling of natural resources has direct environmental impacts to varying
151 degrees, we recommend not using the potentially misleading term "green lithium".

152

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271

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278

279 **Author contributions**

280 A.R. designed the study and drafted the manuscript. A.C. revised the draft manuscript. A.R.
281 drafted the final manuscript.

282

283 **Competing interest**

284 The authors declare no competing interest.

**Industrial production
in 2024**

Large-scale production

White lithium
Salt Lakes

Grey lithium
Mines

Rising production

Pink lithium
Recycling

Incipient production

Yellow lithium
Geothermics

Black lithium
Oil and gas

No production

Blue lithium
Seawater

Fig. 1: A colour code and associated non-technical keywords (in italics) for the main types of lithium resources ranked by volume of industrial production in 2024 (arbitrary scale).