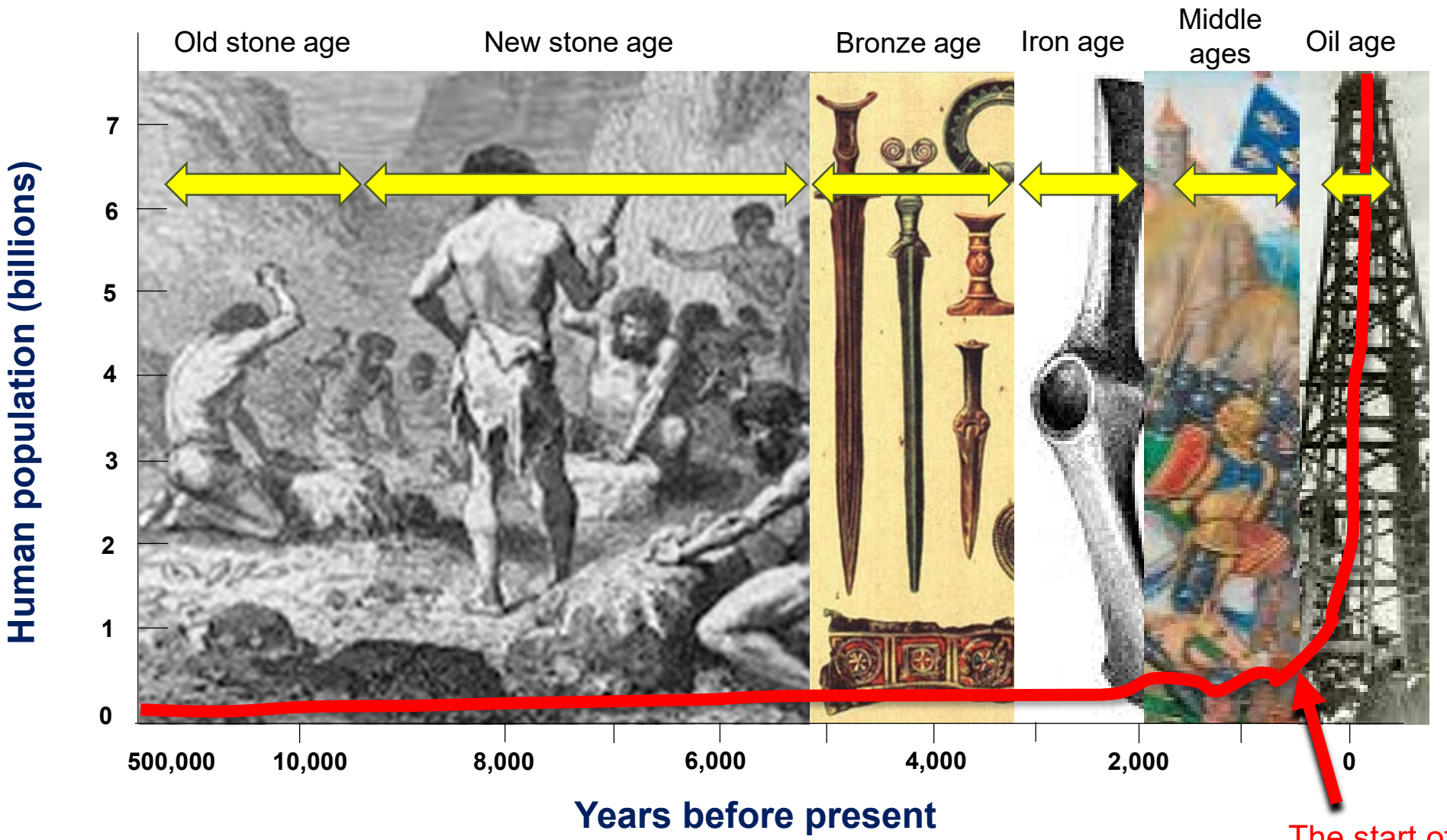
SDU
LIFE CYCLE ENGINEERING

Climate change and the Tragedy of the Commons

Henrik Wenzel, SDU Life Cycle Engineering

Climate Thursdays,
October 5th 2023

Understand growth, development and innovation



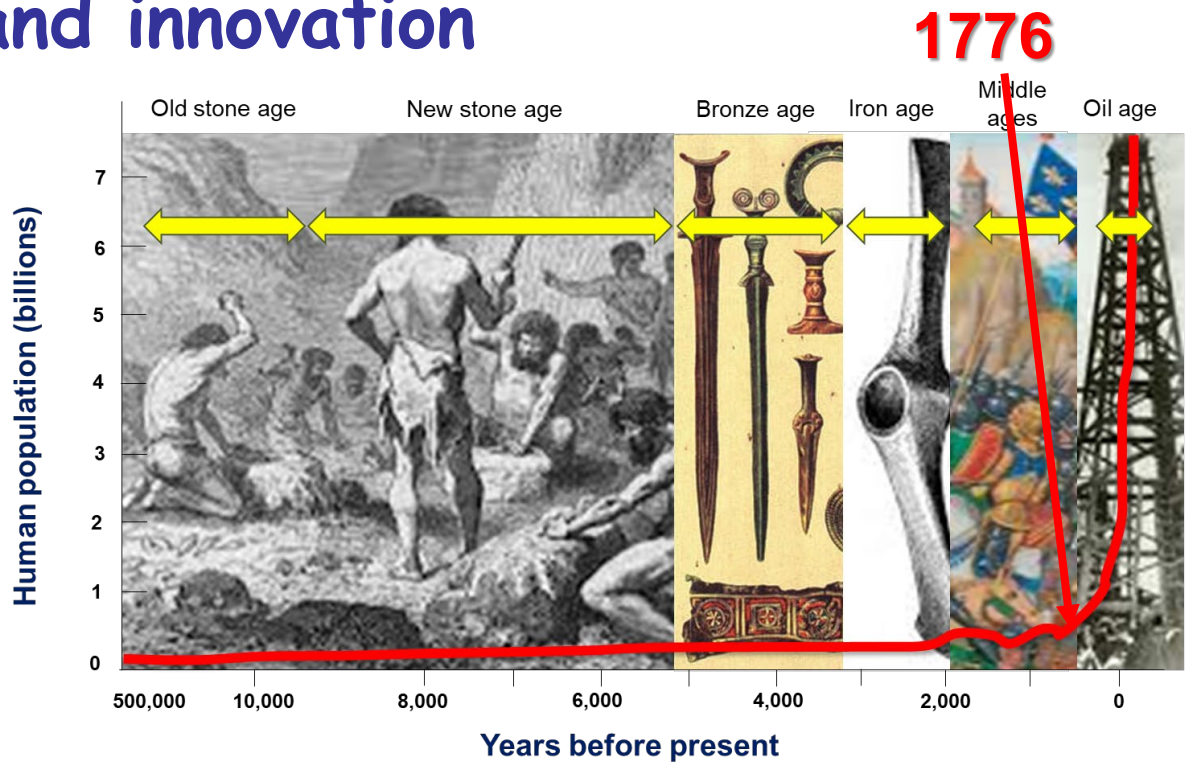
Understand growth, development and innovation

- the industrial revolution

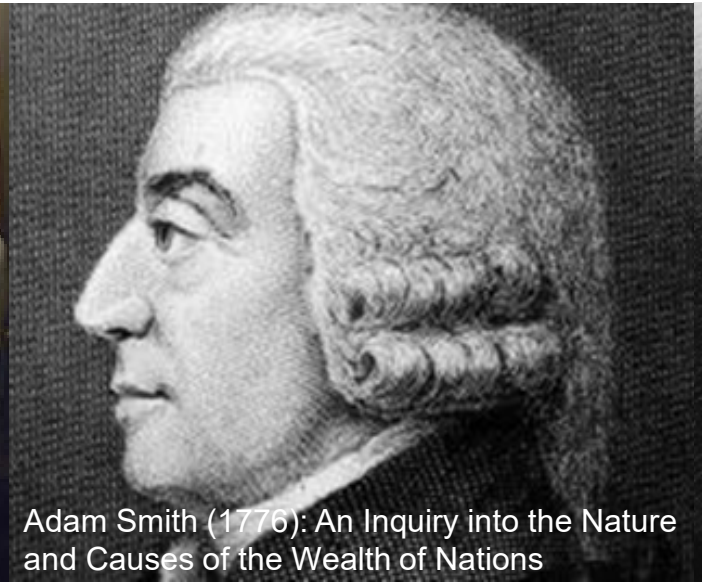
One lesson learned: "we didn't leave the stone age due to a lack of stones…"

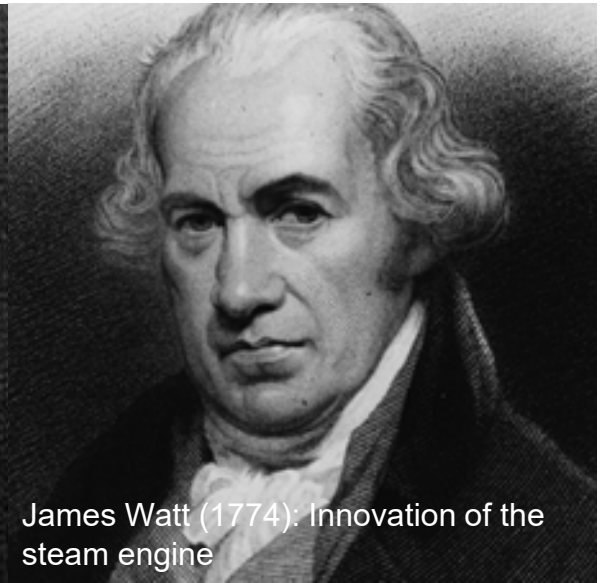
… no, we left an era, because something better always came up

But why does something better always come up? And will something better than the 'fossil fuel age' automatically come up?



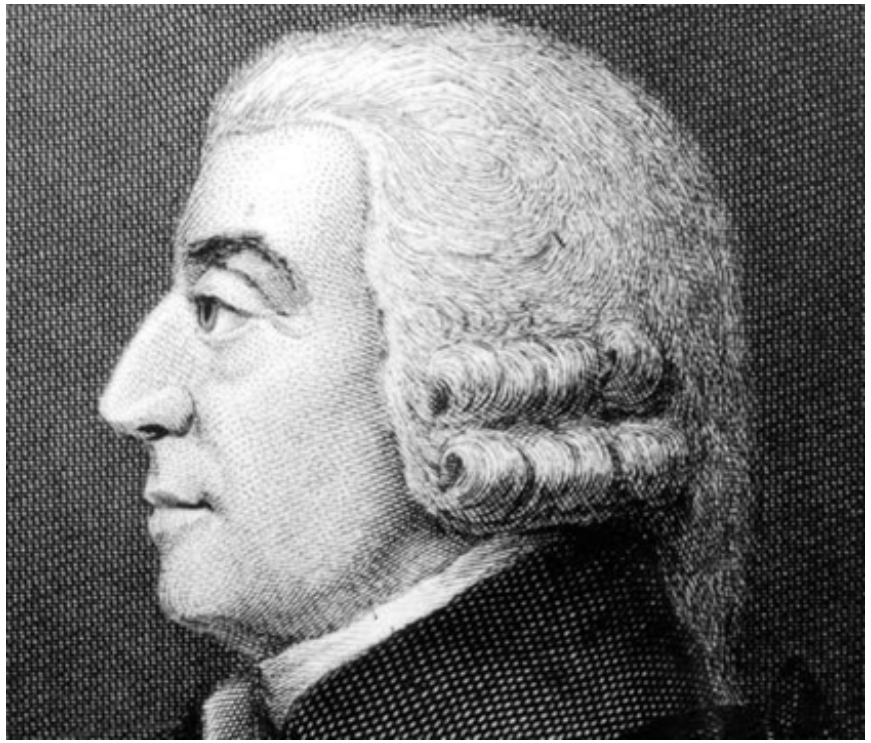

USA (1776): The declaration of independance


Adam Smith (1776): An Inquiry into the Nature and Causes of the Wealth of Nations


James Watt (1774): Innovation of the steam engine

Coal mining: Large scale from beginning of industrial revolution

Mechanism of innovation – and evolution



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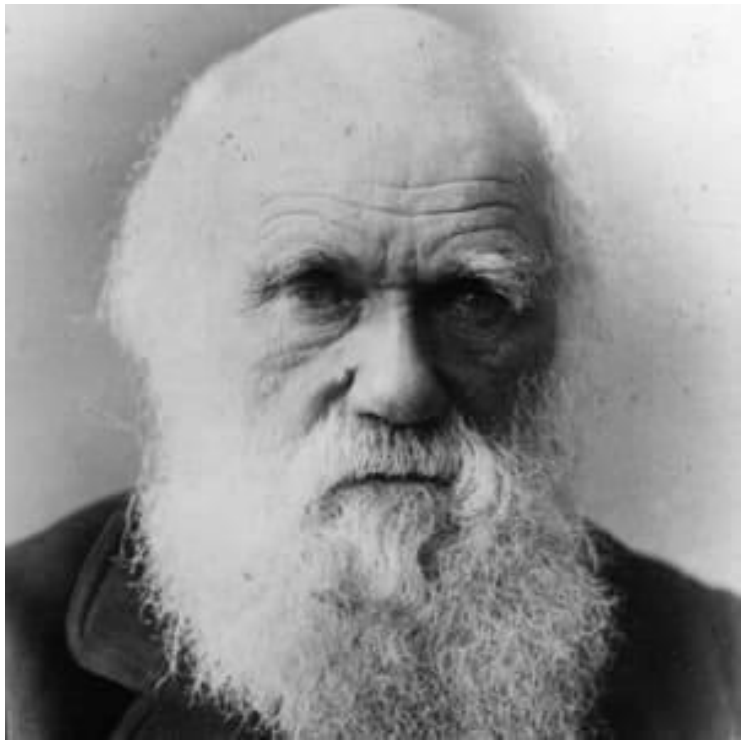

Darwin C (1859): On the origin of species…

Common mechanisms in evolution and innovation: competition and ‘survival of the fittest’

Adam Smith: market economy as an ‘invisible hand’ leading to ever better solutions for the common good of the individual and of society as a whole

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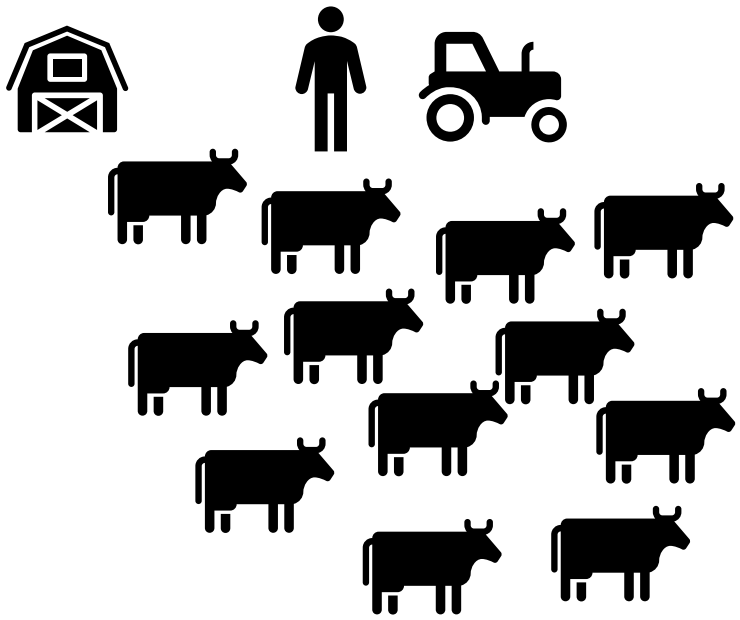
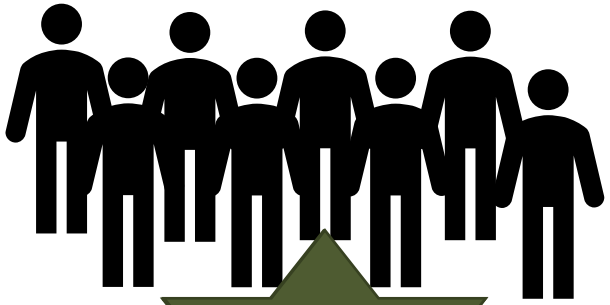
The Invisible Hand

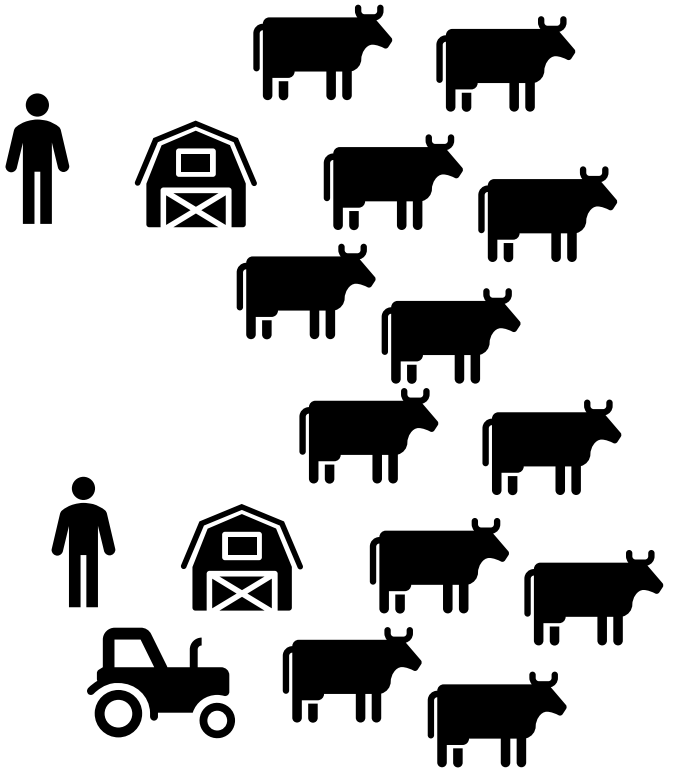
Adam Smith

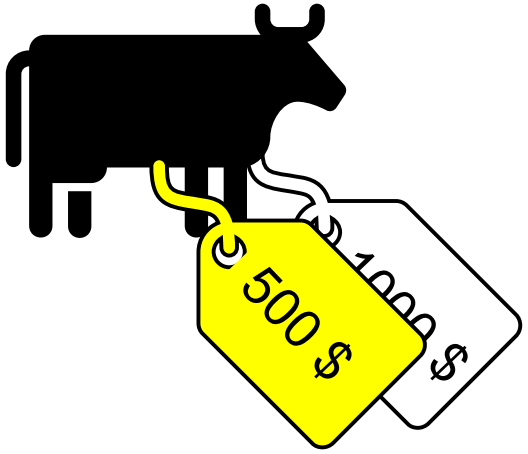
The Invisible Hand

Adam Smith









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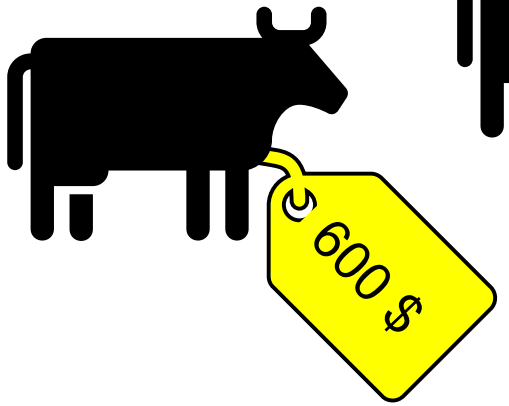

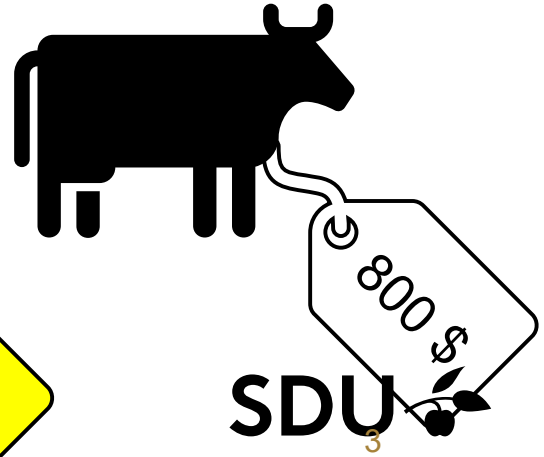

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Understand growth, development and innovation

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Lesson learned: "we didn't leave the stone age due to a lack of stones…"

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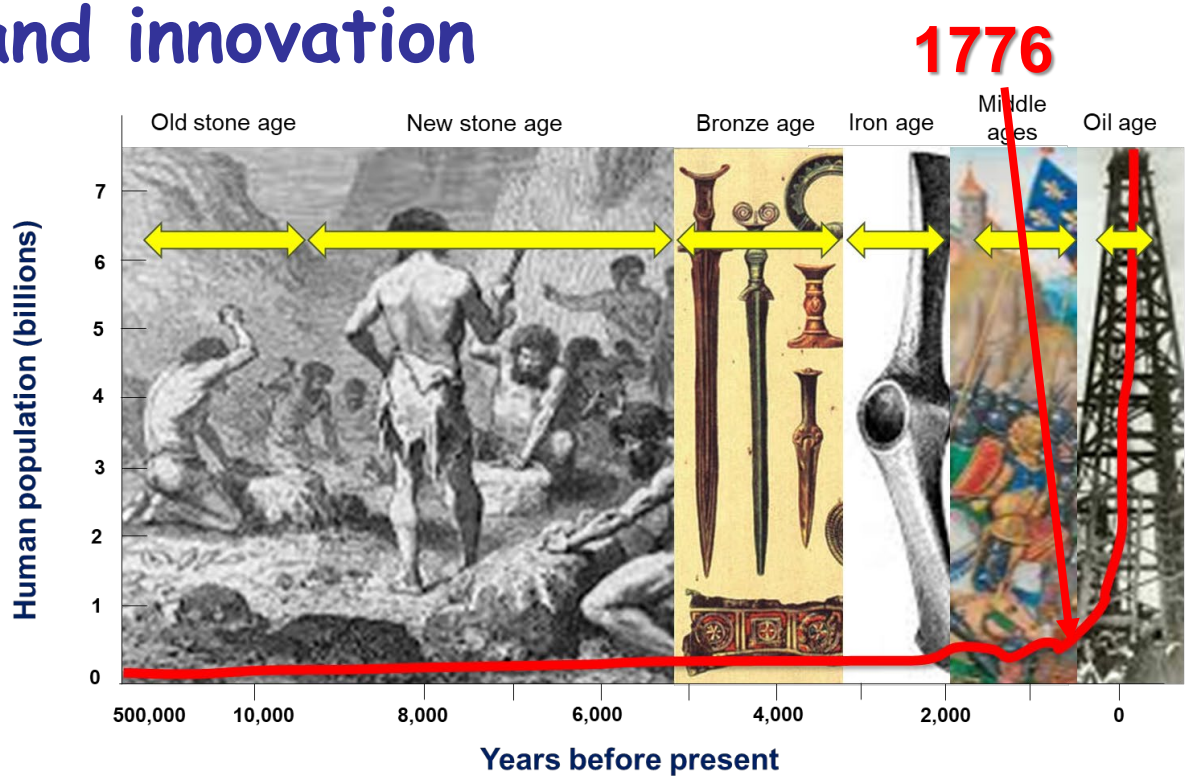
But why does something better always come up? And will something better than the 'fossil fuel age' automatically come up?

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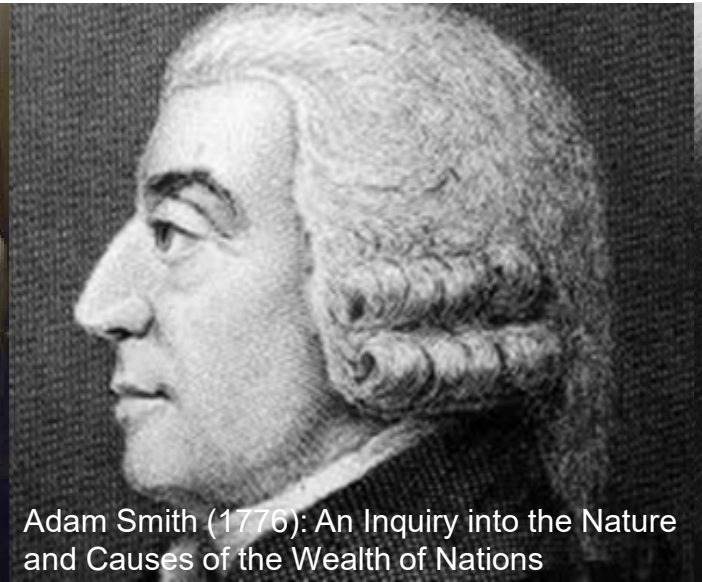
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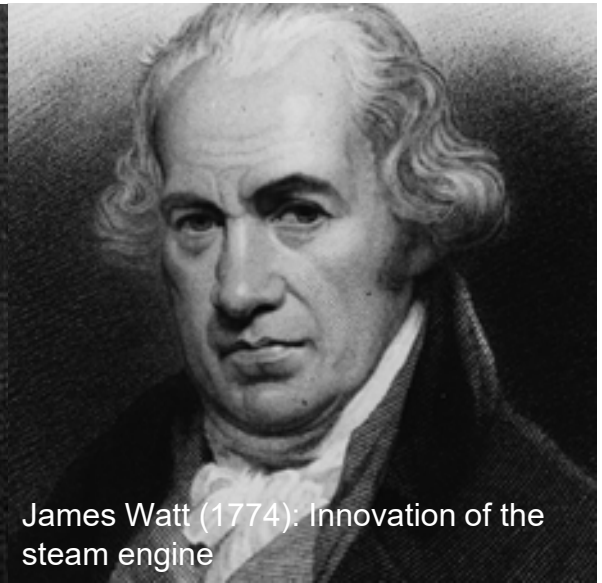
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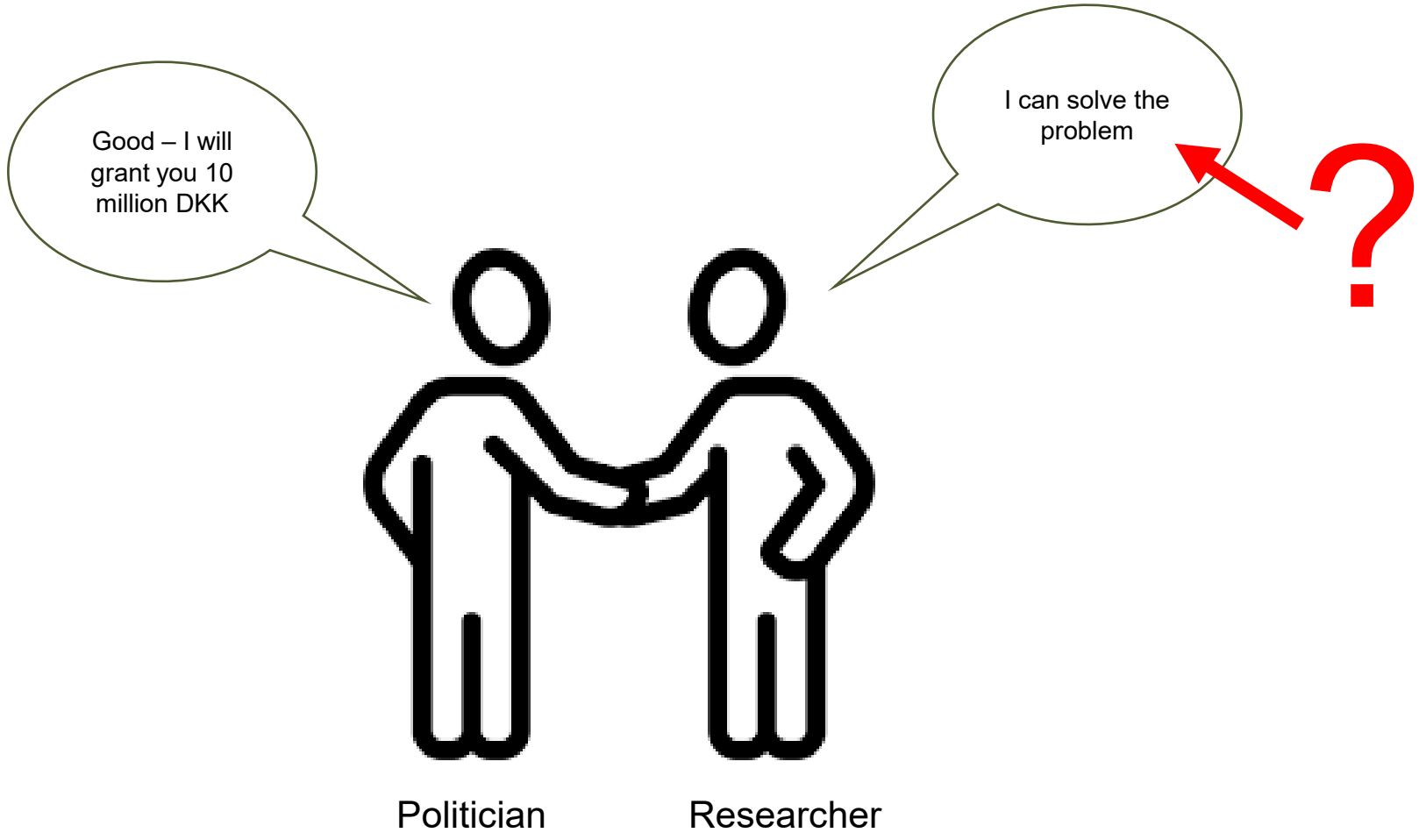
Will something better than fossil fuels come up?

- the ‘unfortunate alliance’

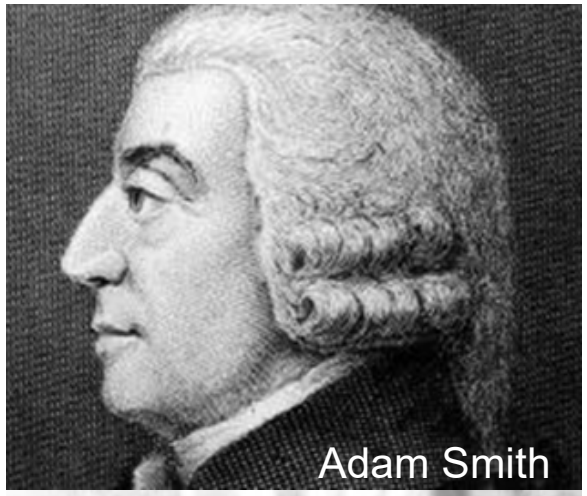


The Tragedy of the Commons

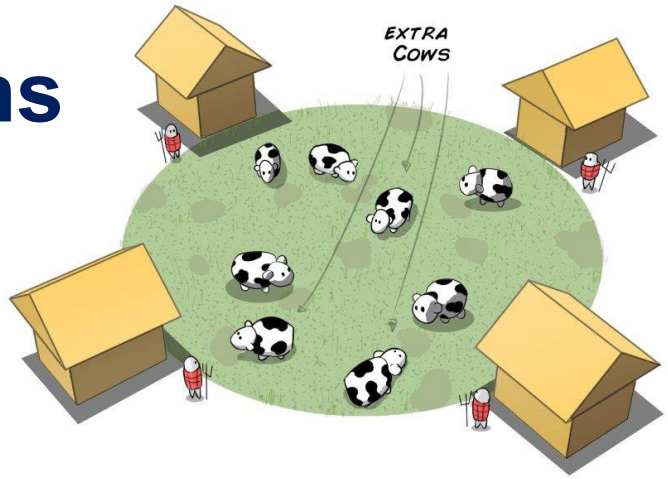
Competition and survival of the fittest on the market will always lead to innovation and better solutions for all society.

It is like an 'invisible hand' – we do not need to regulate.

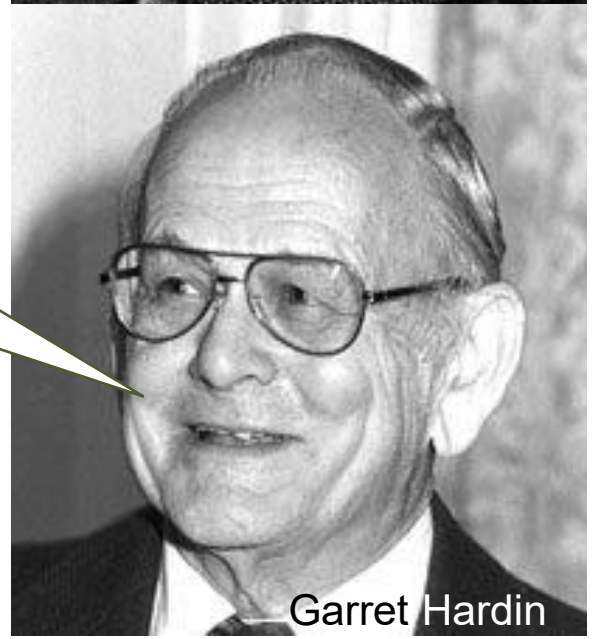
Selfishness and individual optimization among suppliers to the market leads to societal optimum



The Commons



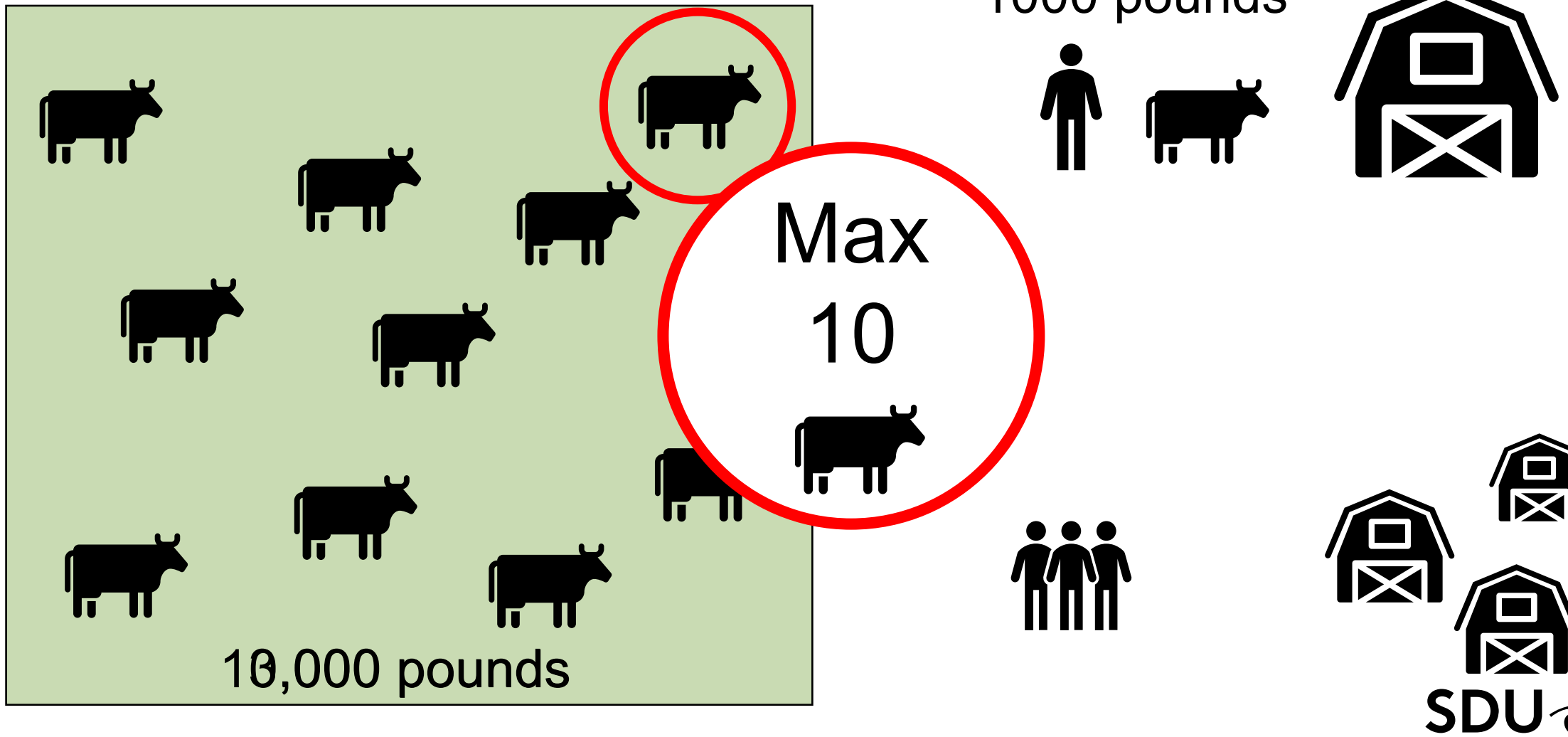
No, not always. Not in a Tragedy of the Commons type of situation



Hardin G (1968): The Tragedy of the Commons. *Science*

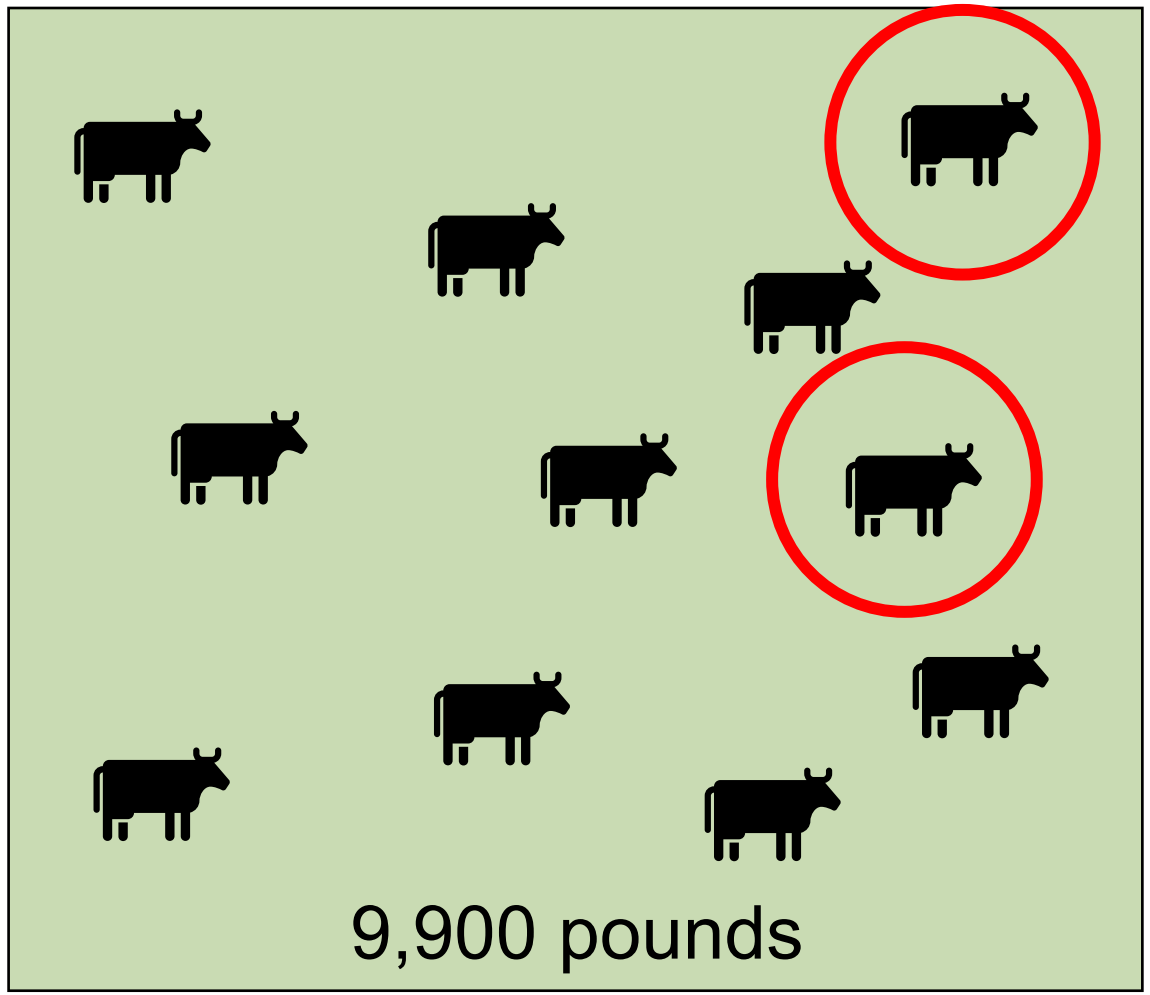
The Tragedy of the Commons

Garret Hardin, (1968)

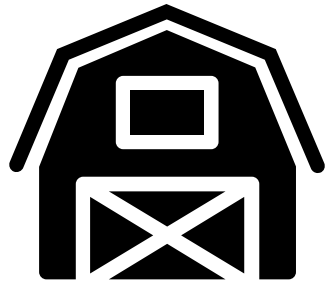


The Tragedy of the Commons

Garret Hardin, (1968)



+800 pounds



-100 pounds

Understand the Tragedy of the Commons

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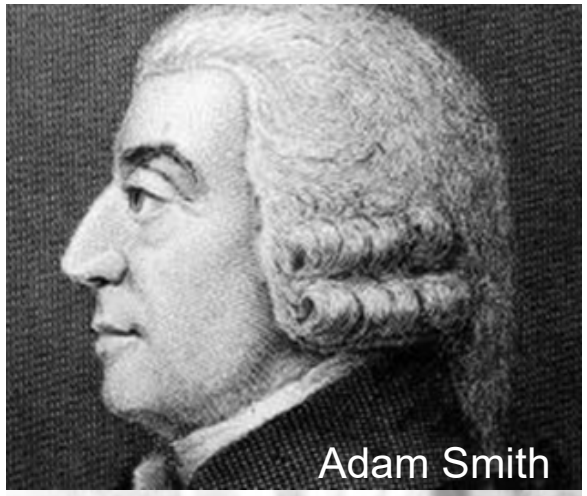
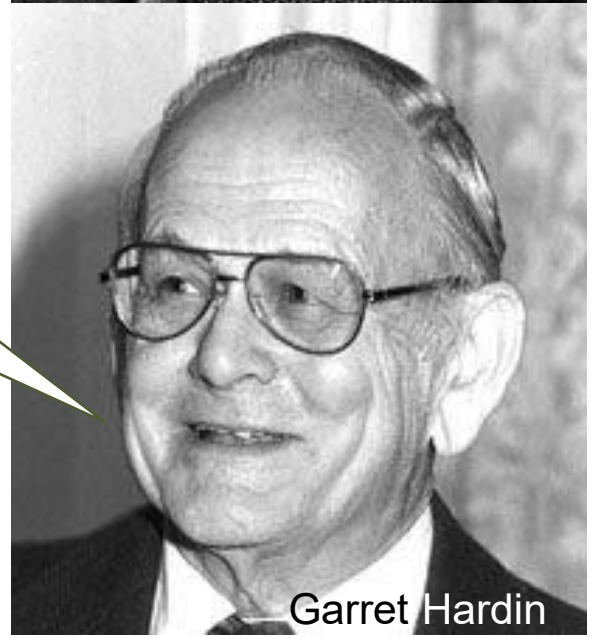
Selfishness and individual optimization among suppliers to the market leads to societal optimum


Adam Smith

No, - not always, as I said … and fishery is another example…


Garret Hardin

We need quota and regulation to achieve societal optimum

What are the criteria for an economic activity being a Tragedy of the Commons?

1. The resource supporting the economic activity in question is a ‘common pool resource’
2. The common pool resource has a threshold, above which the ability of the resource to sustain the activity will decrease and eventually disappear
3. There is no competitive alternative to the economic activity in question

…is Climate Change a Tragedy of the Commons type of challenge?

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1. Common-pool resource?

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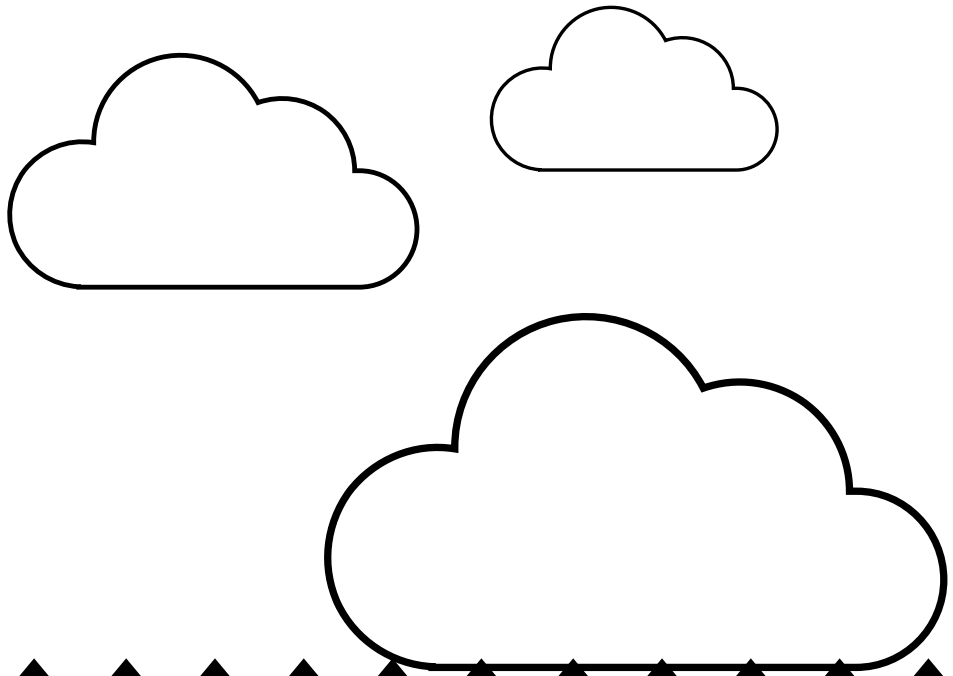
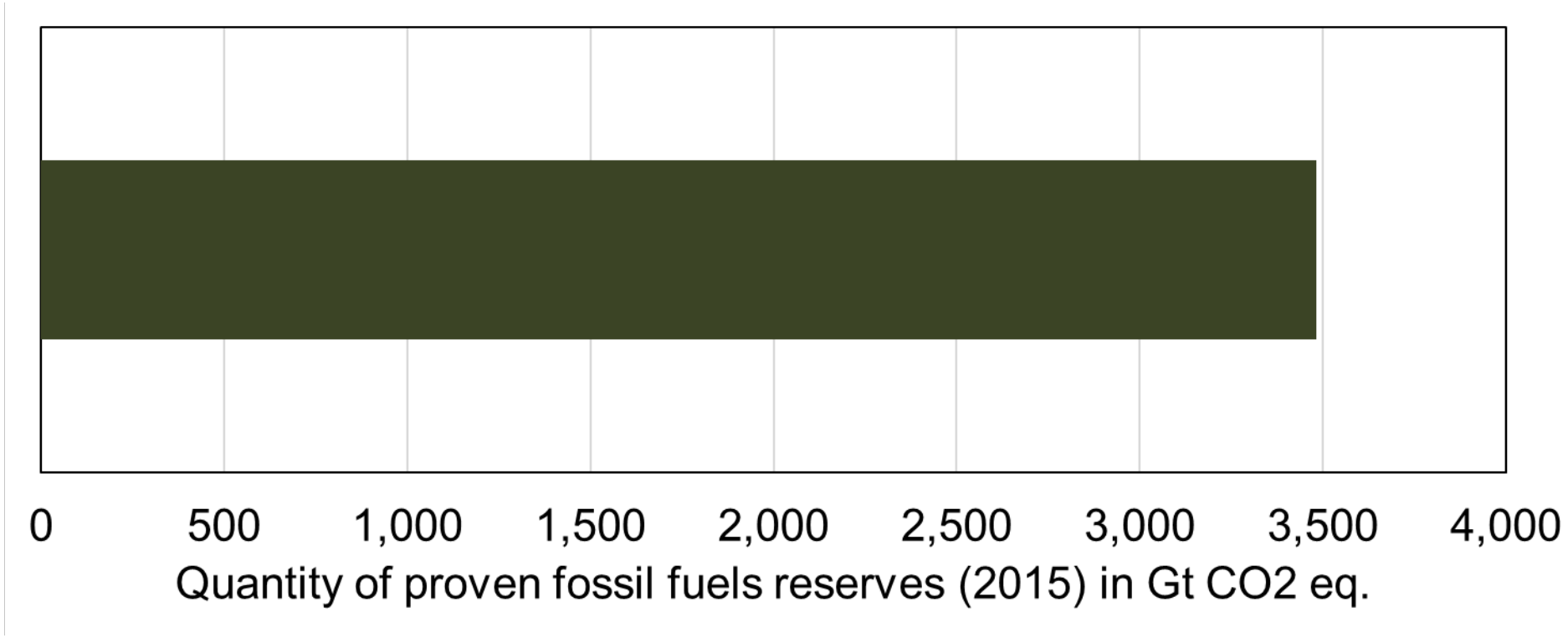
The atmosphere



2. Violating the carrying capacity?

Fossil fuels and the temperature limits

BGR, (2016)



Fossil fuels and the temperature limits

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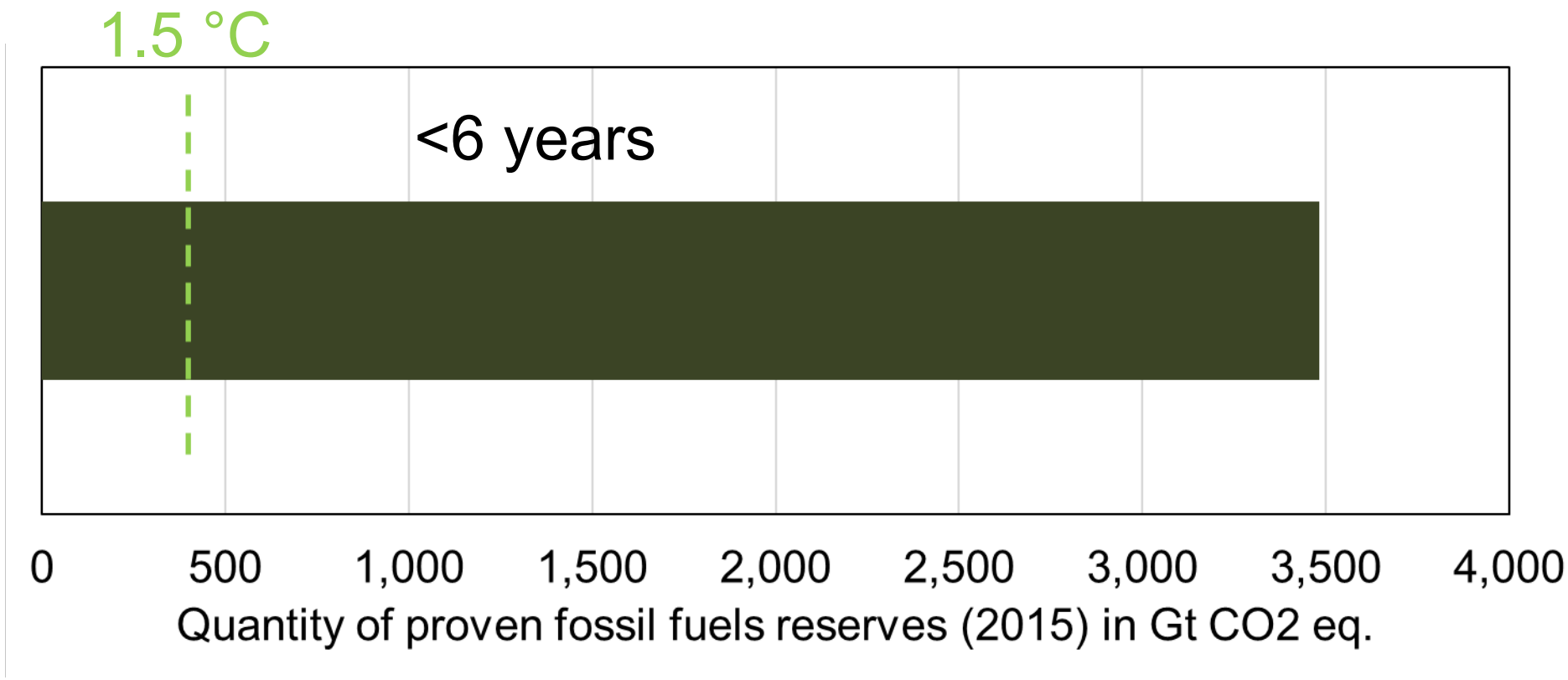

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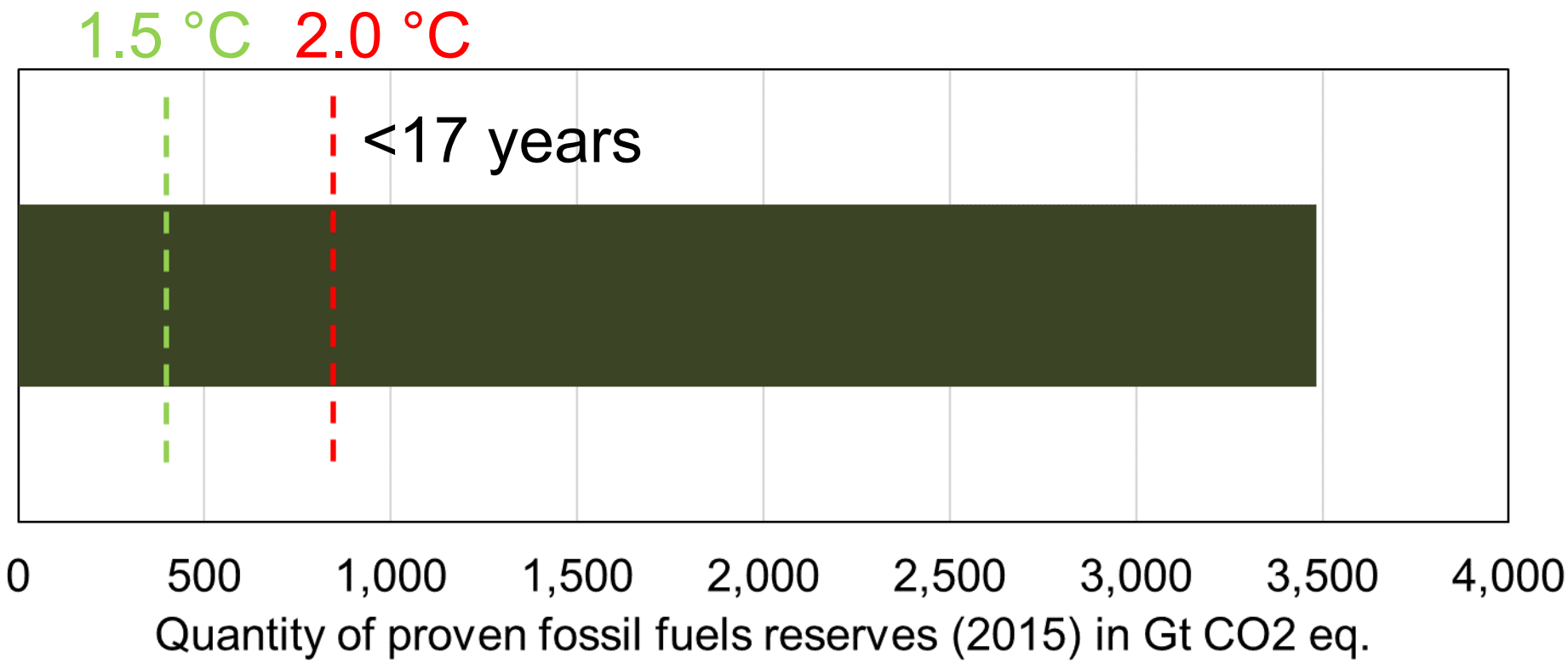

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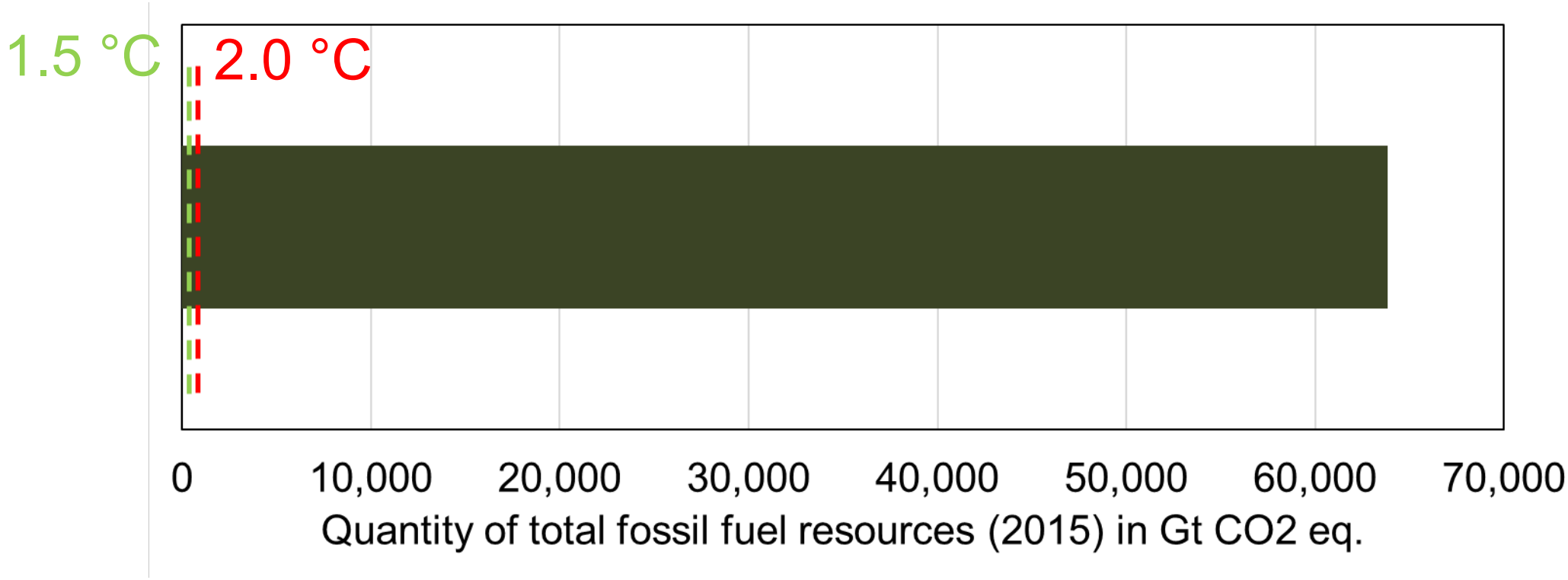
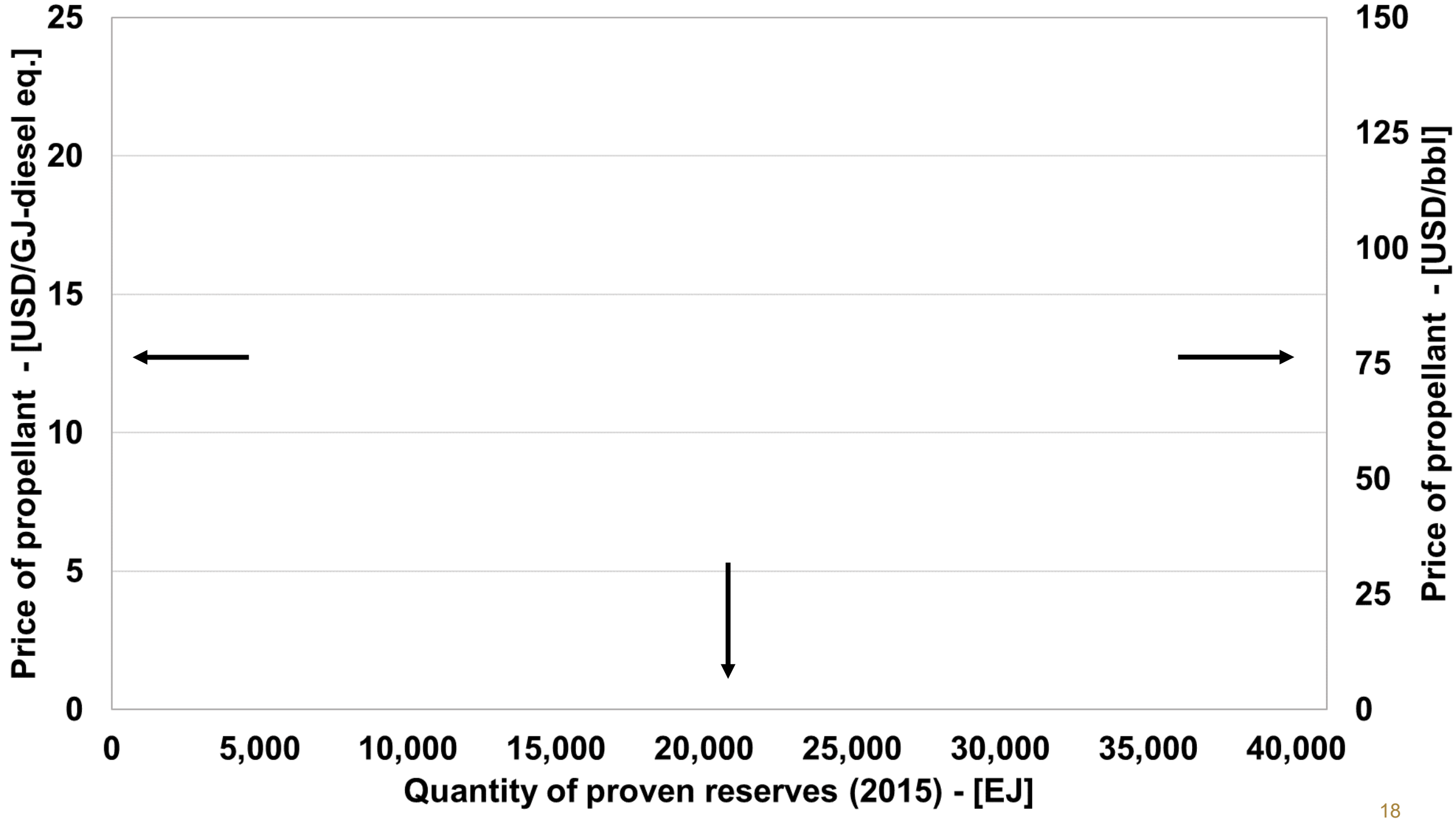


3. Feasible technical solutions?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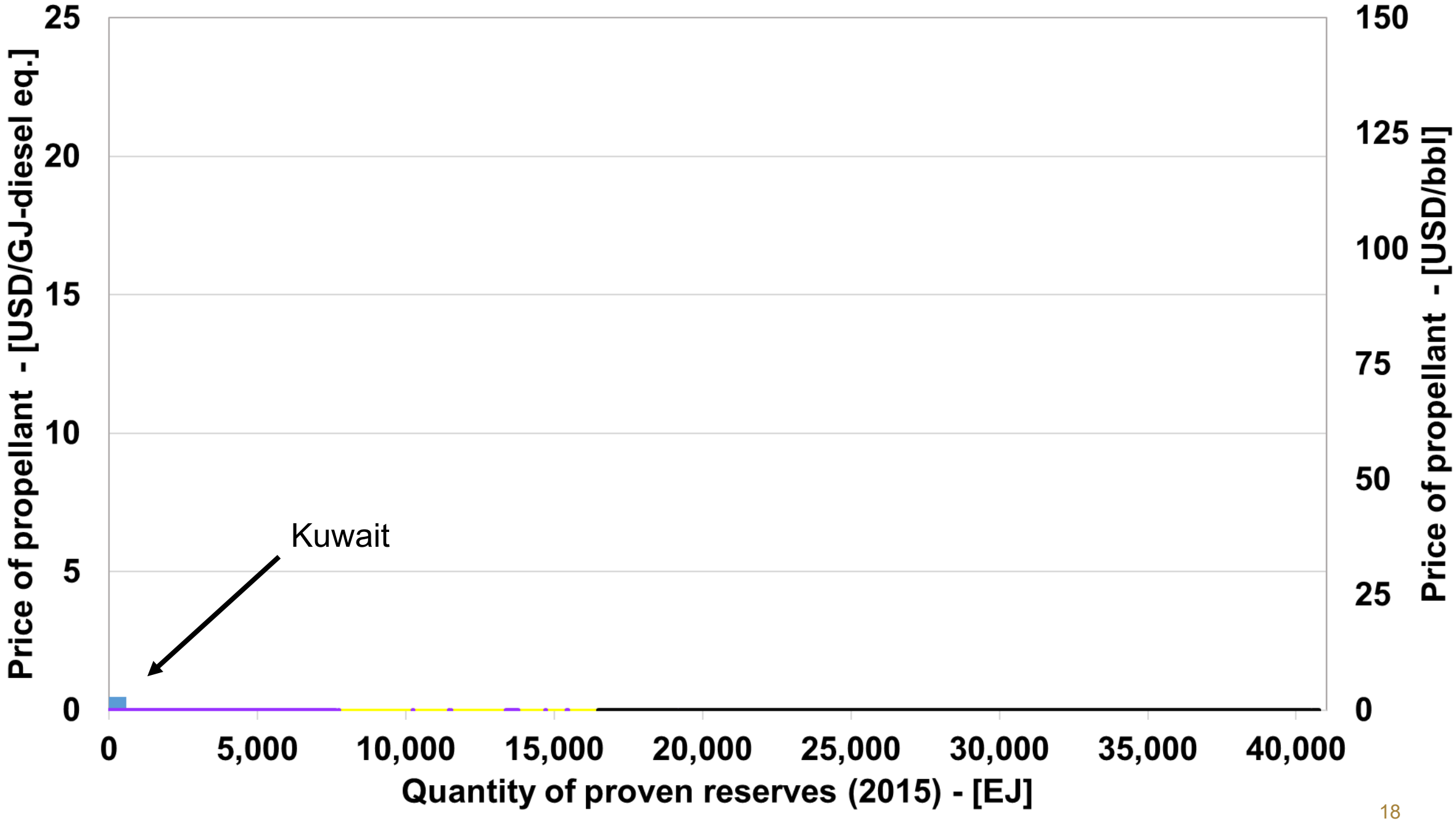
Quantity of proven reserves (2015) - [EJ]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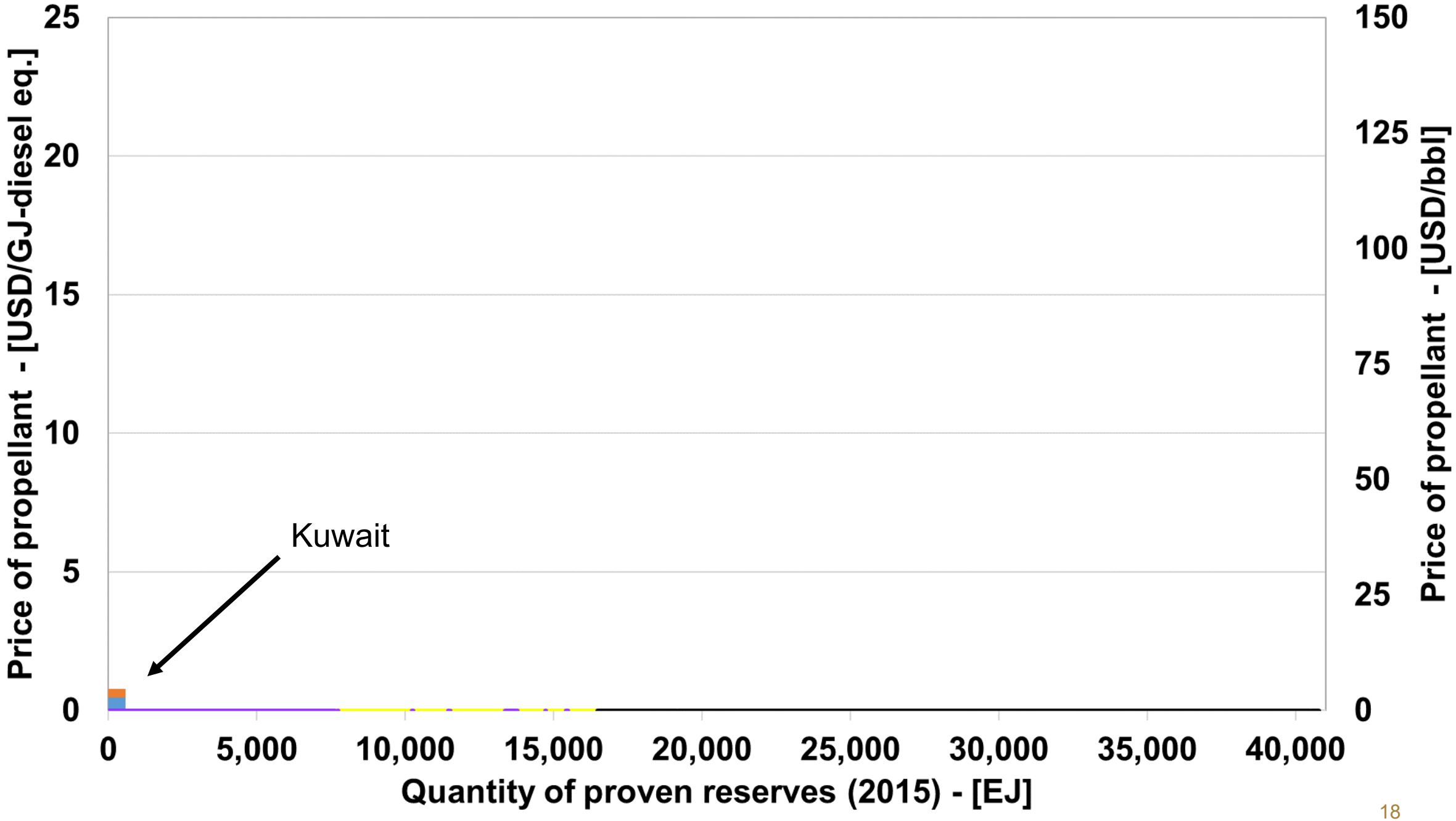
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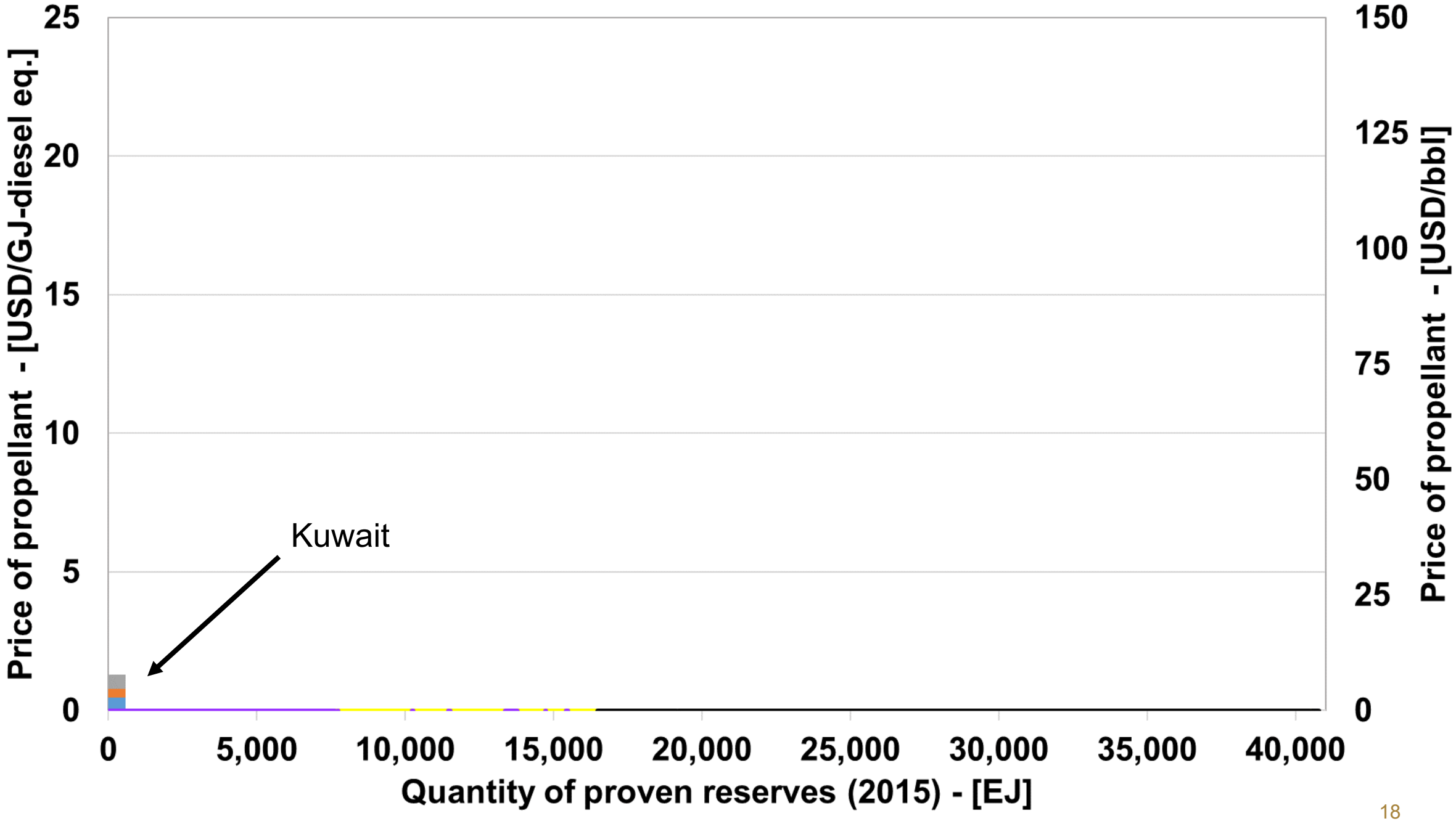
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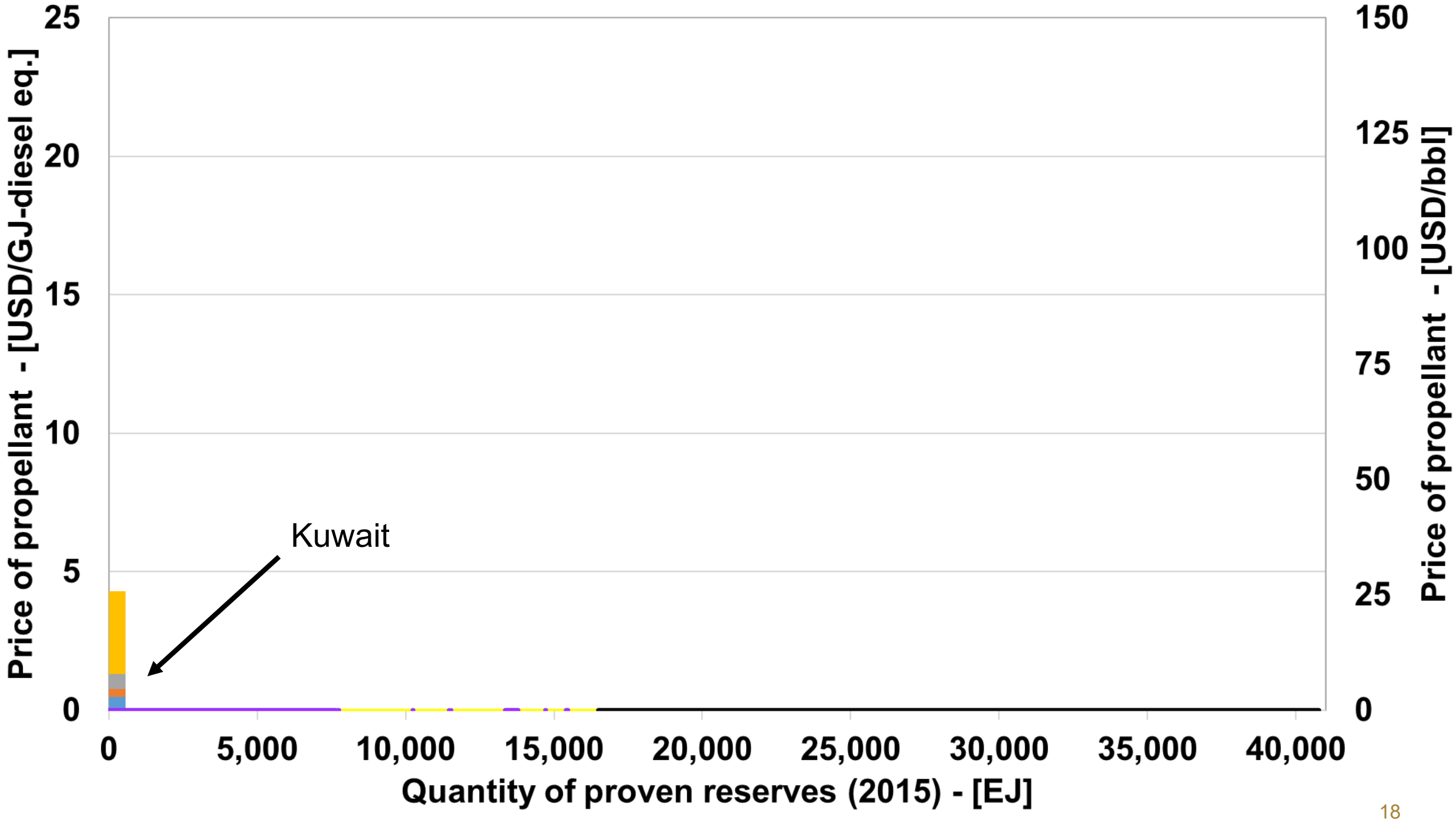
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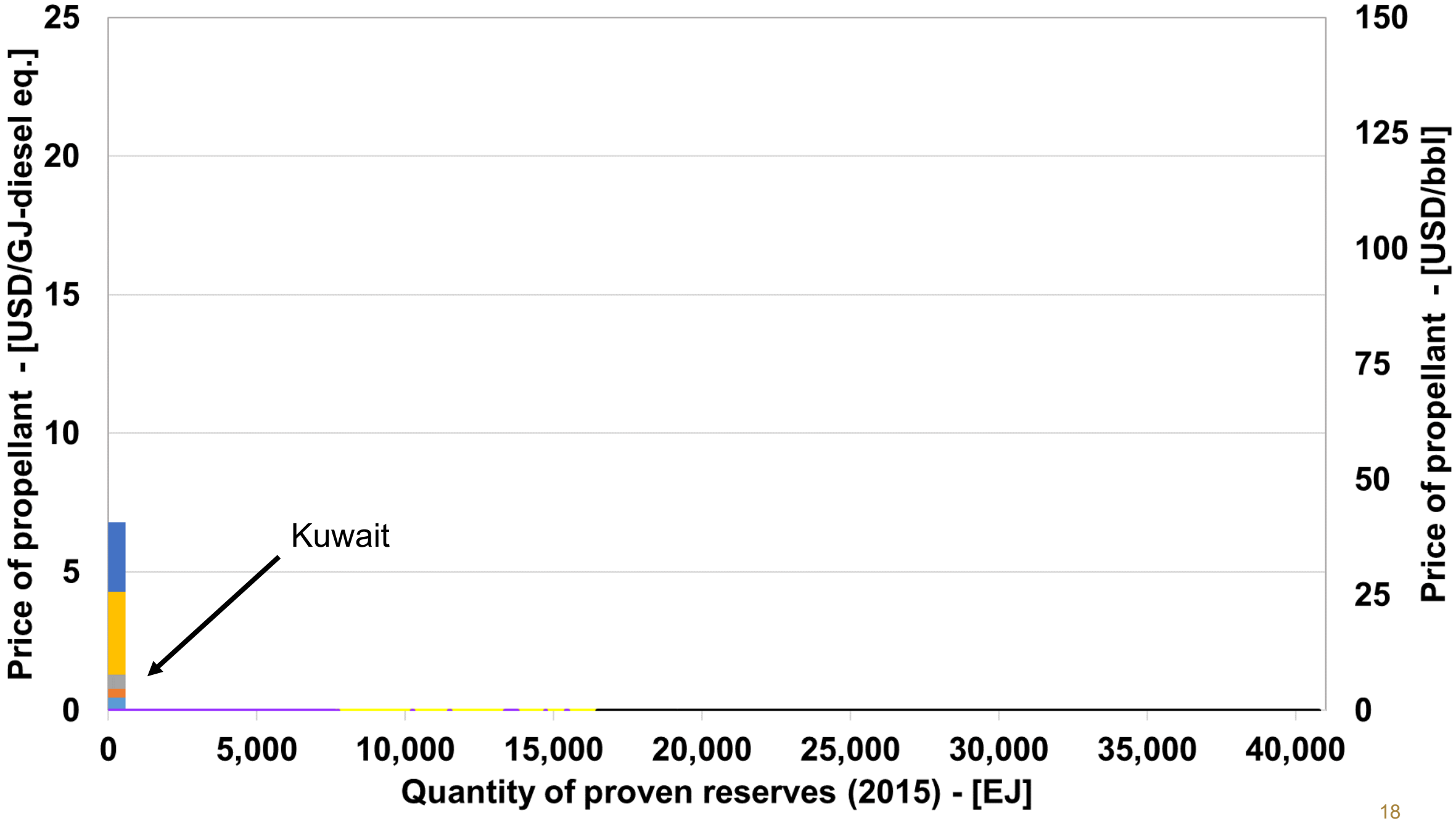
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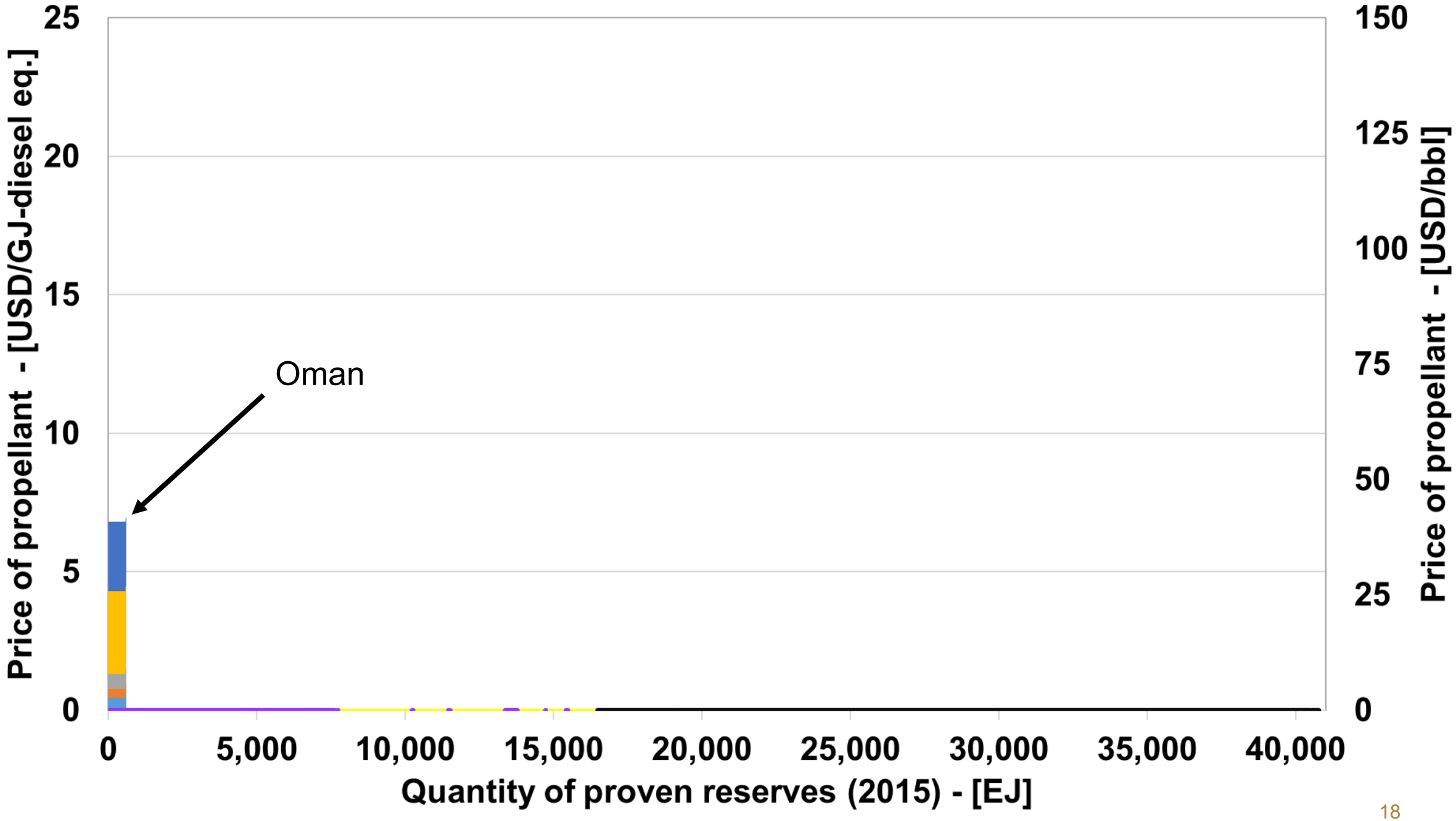
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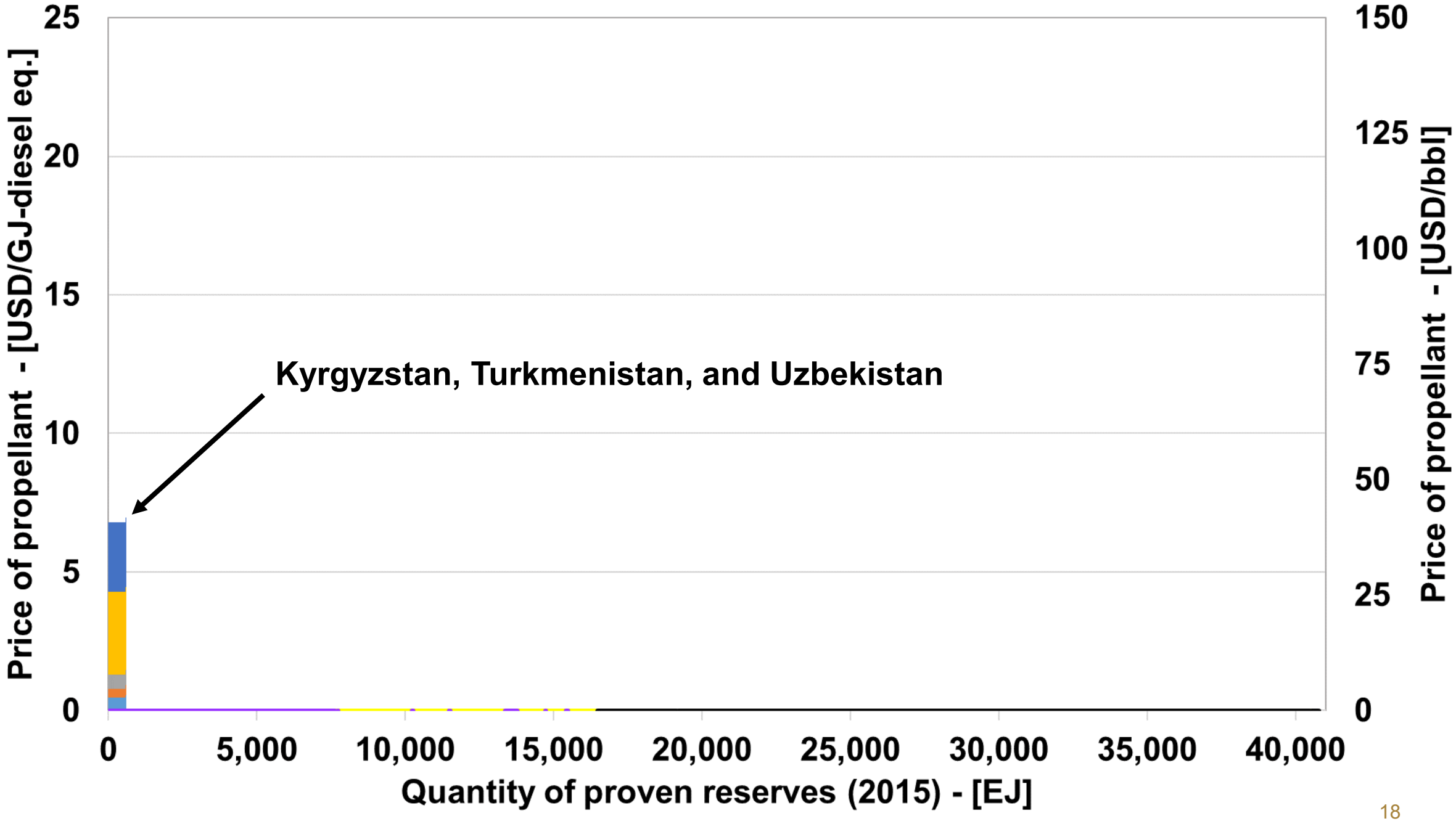
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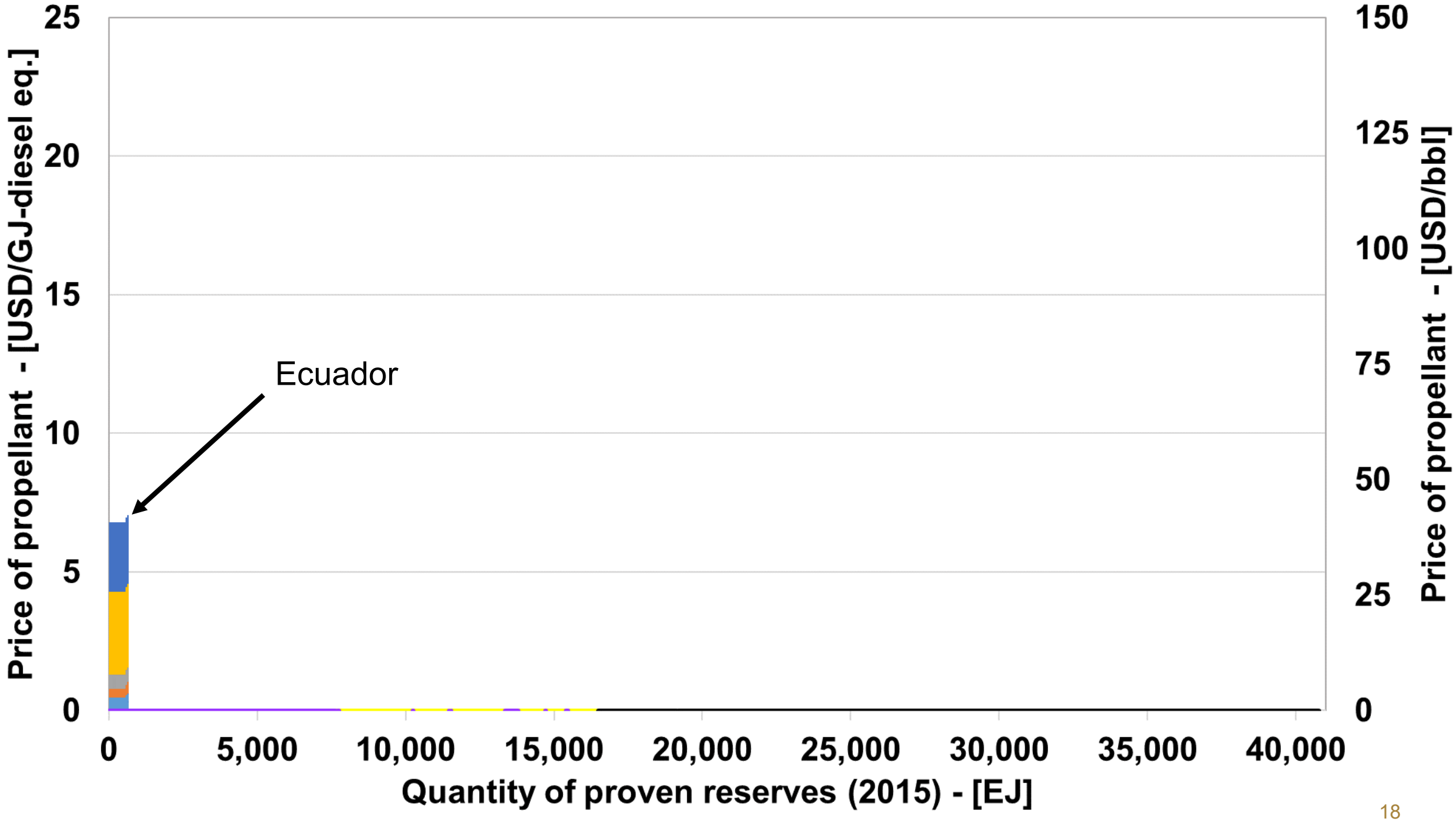
Price of propellant - [USD/GJ-diesel eq.]
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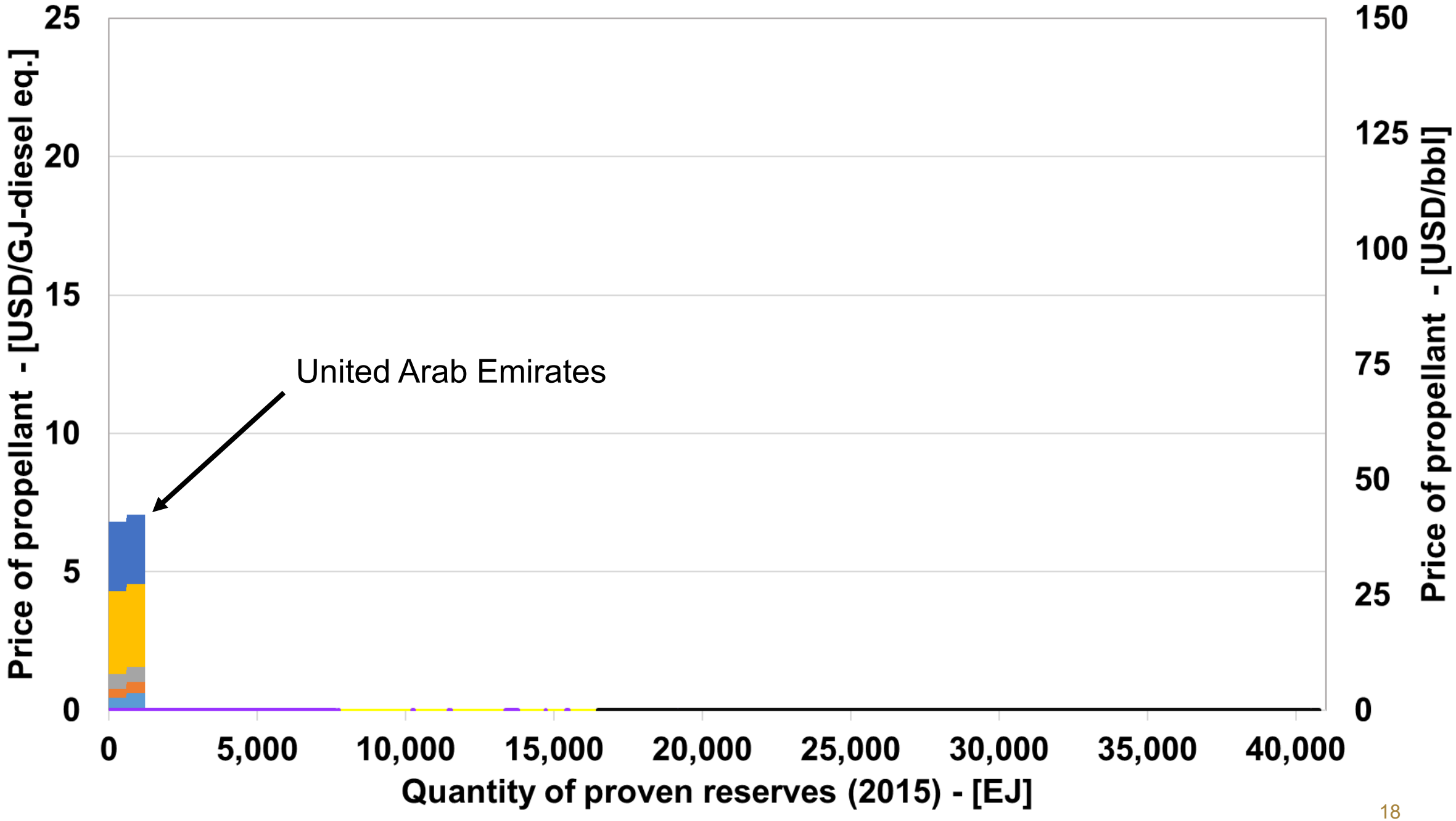
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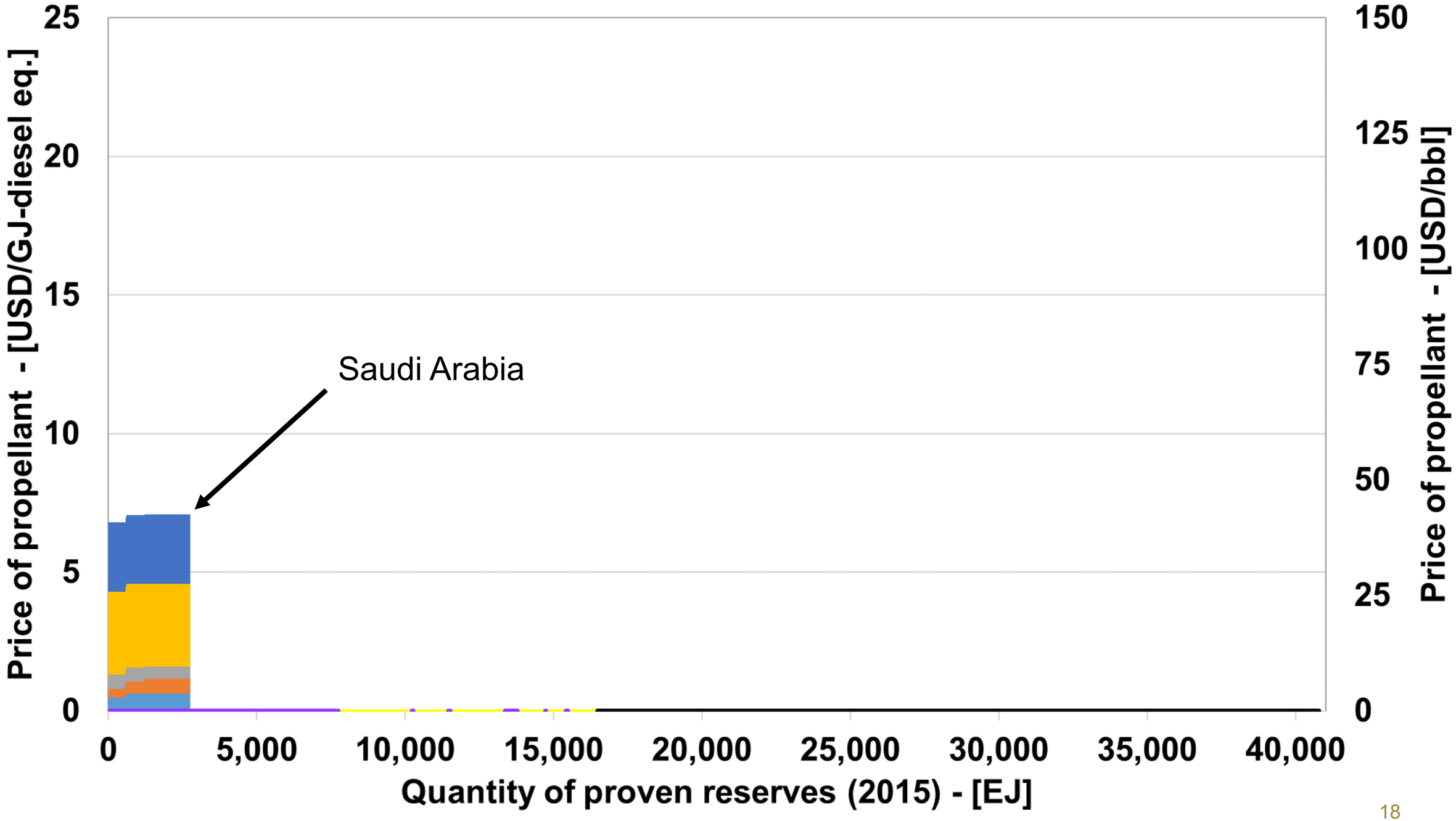
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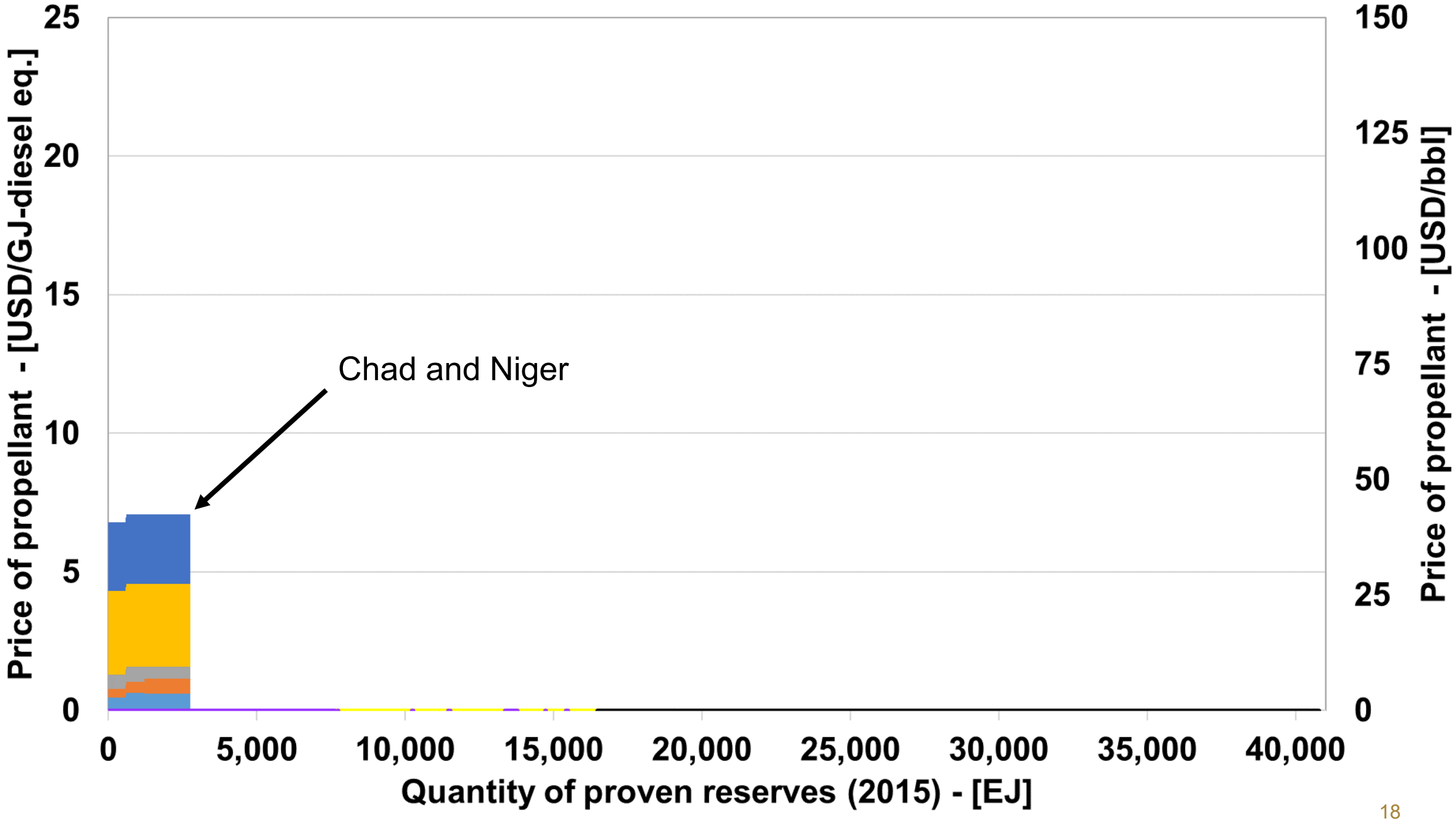
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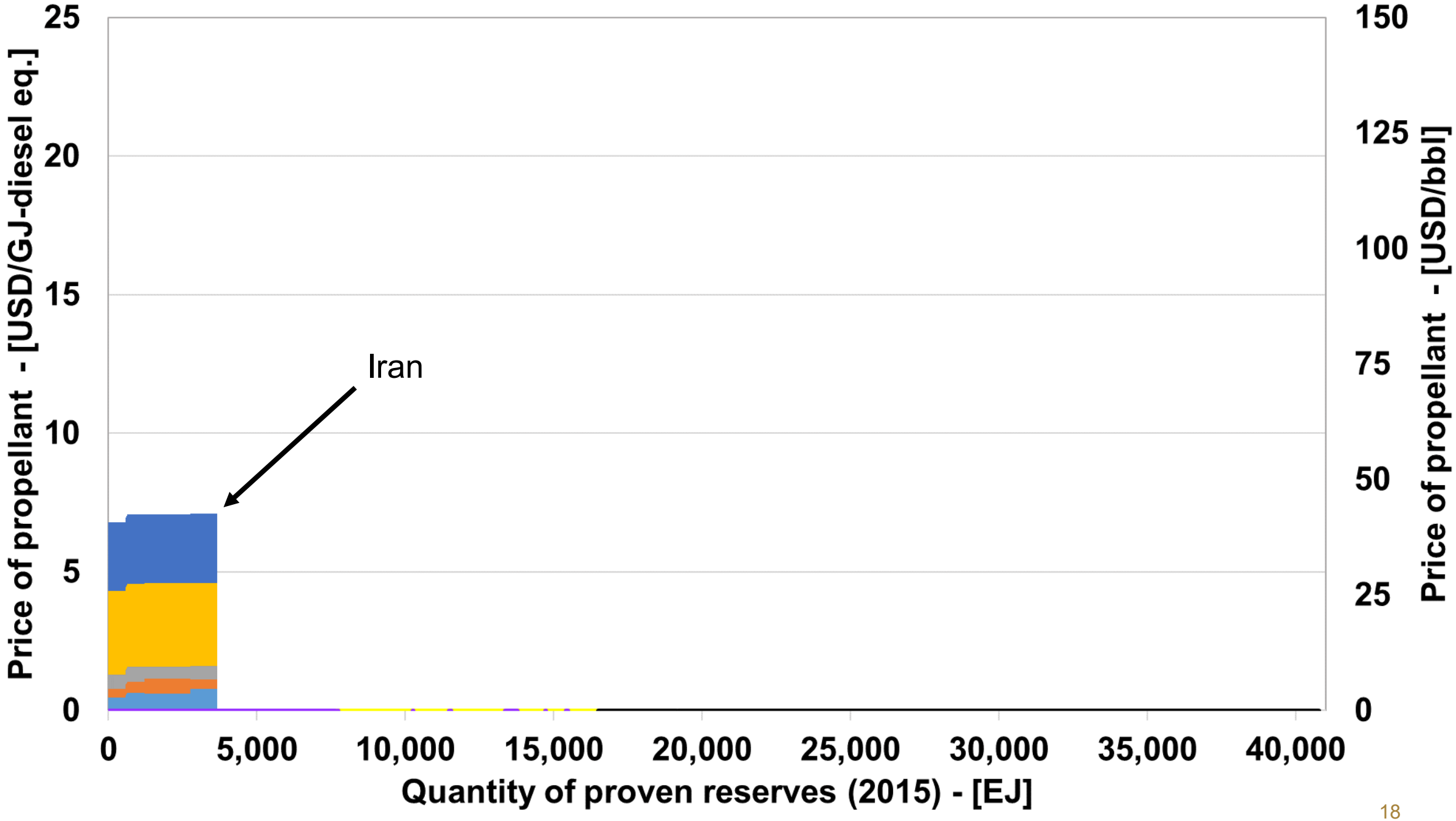
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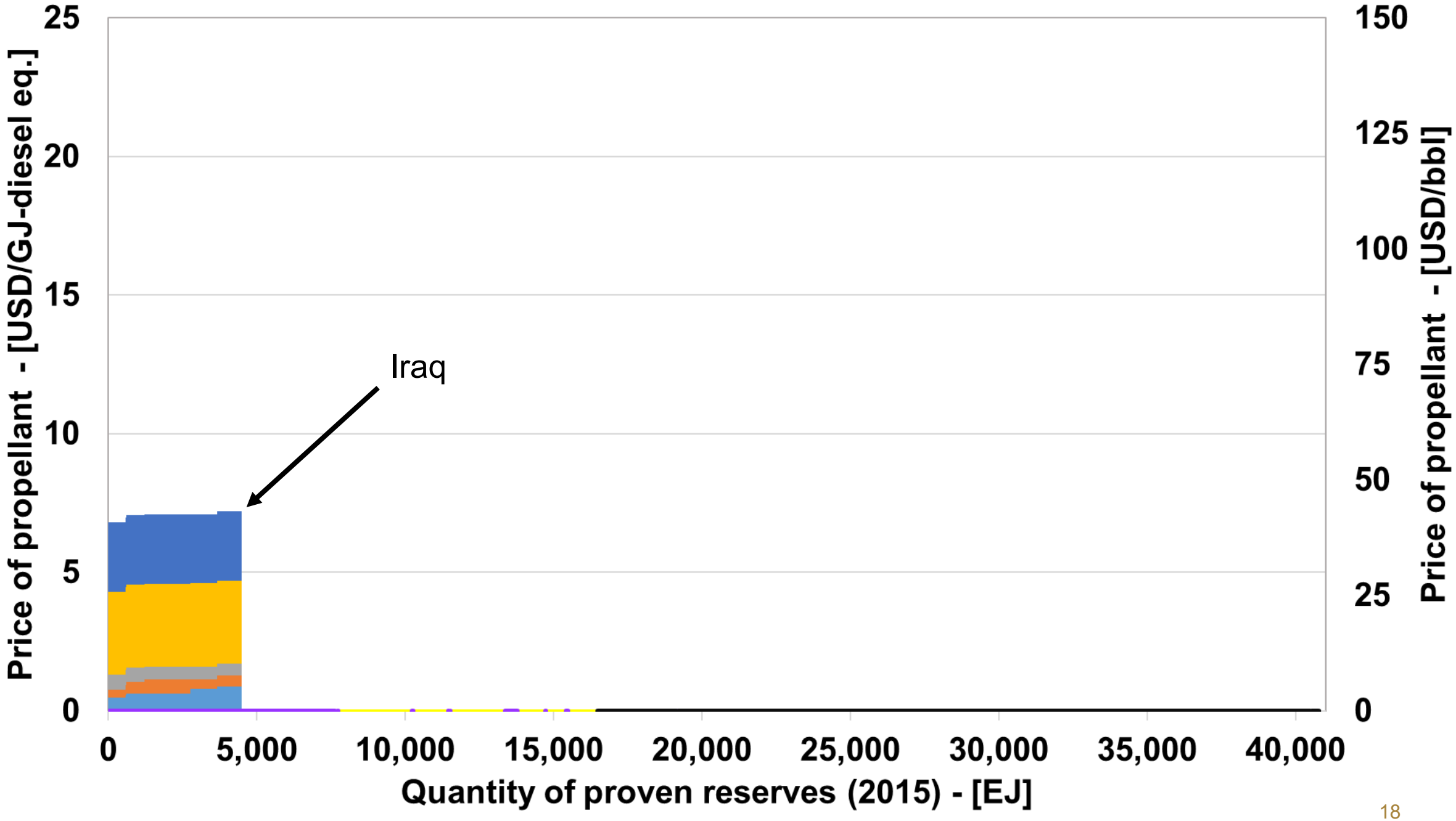
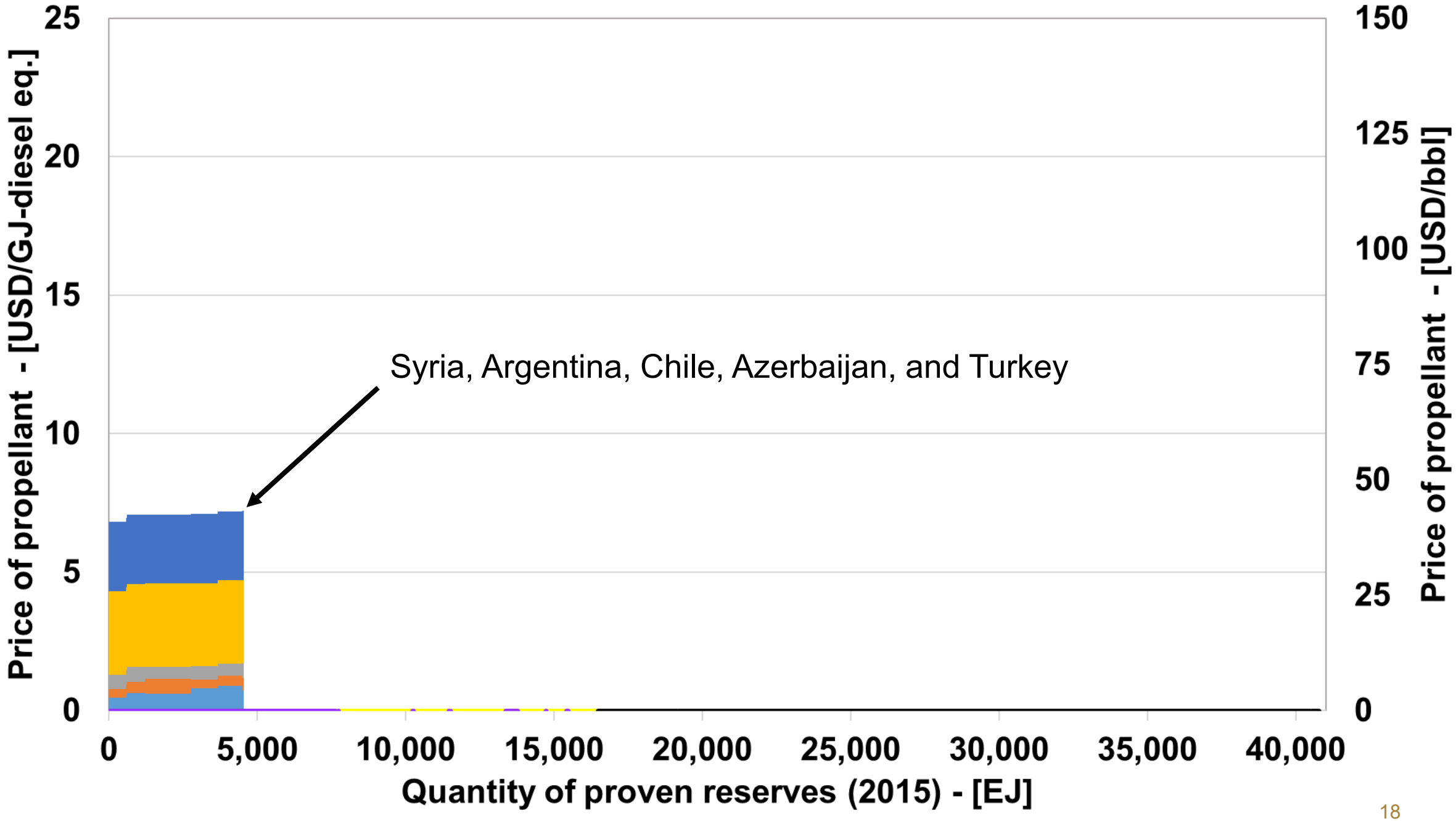
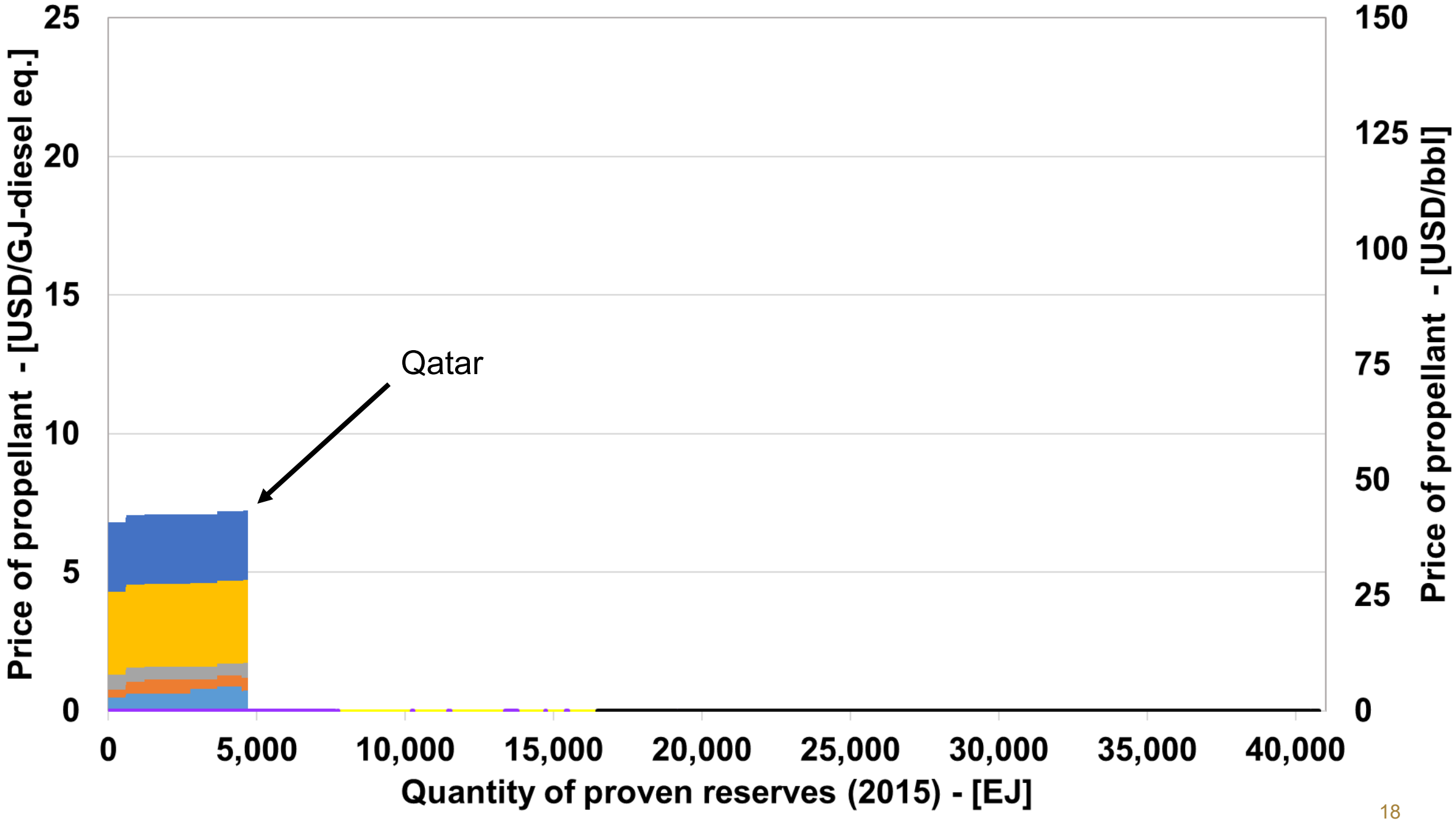
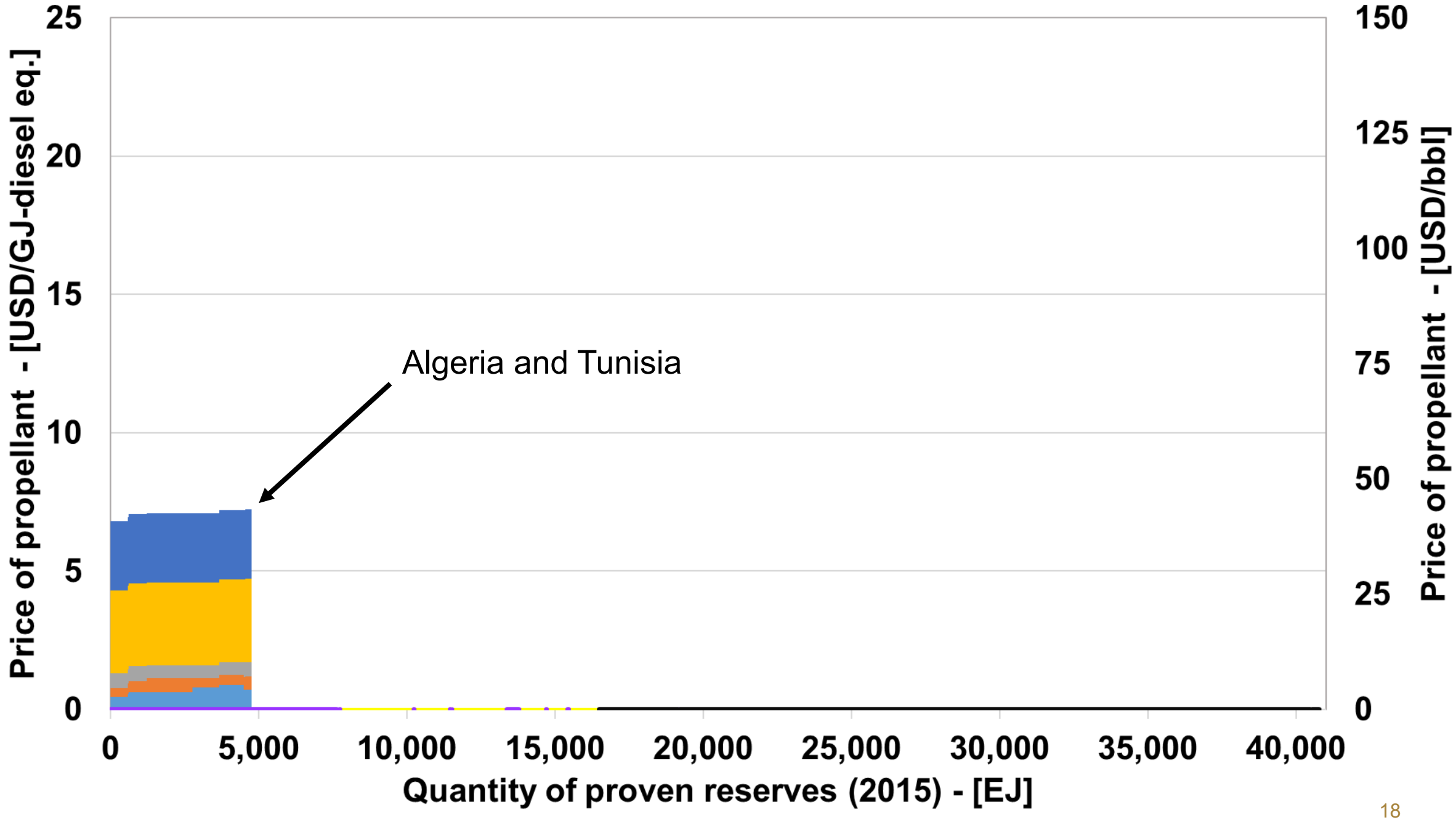
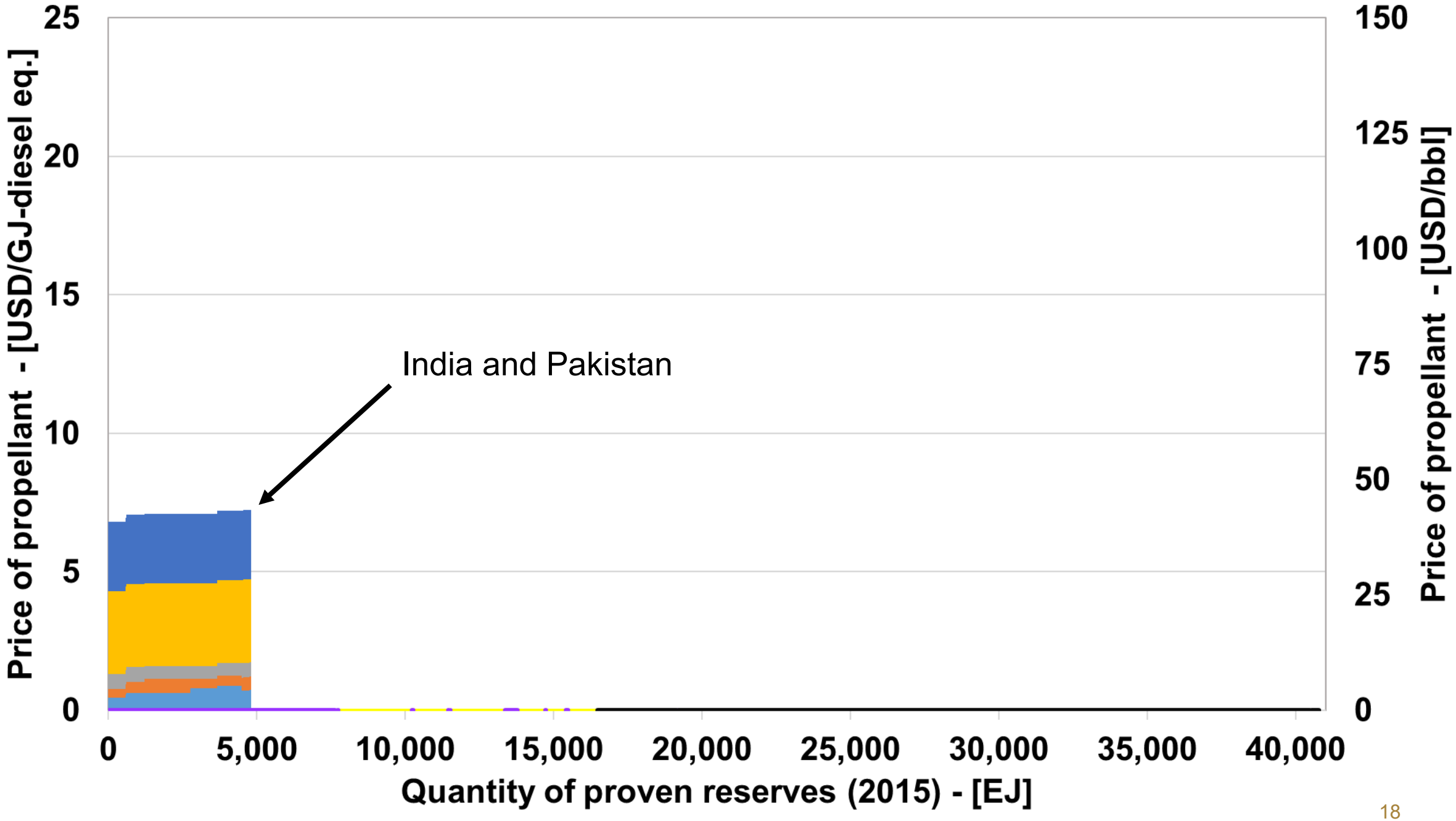
0
Price of propellant - [USD/bbl]

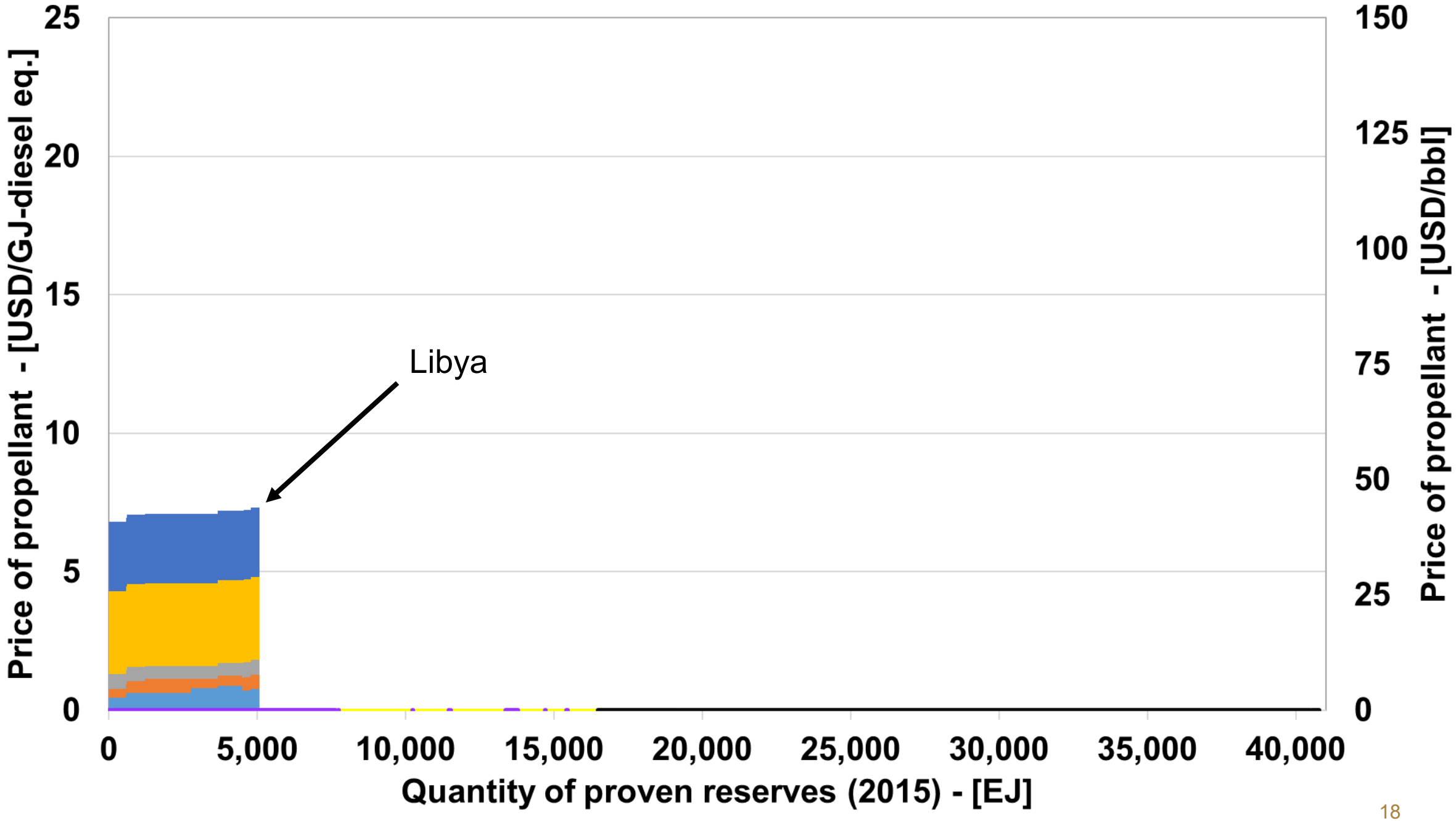

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Iraq
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

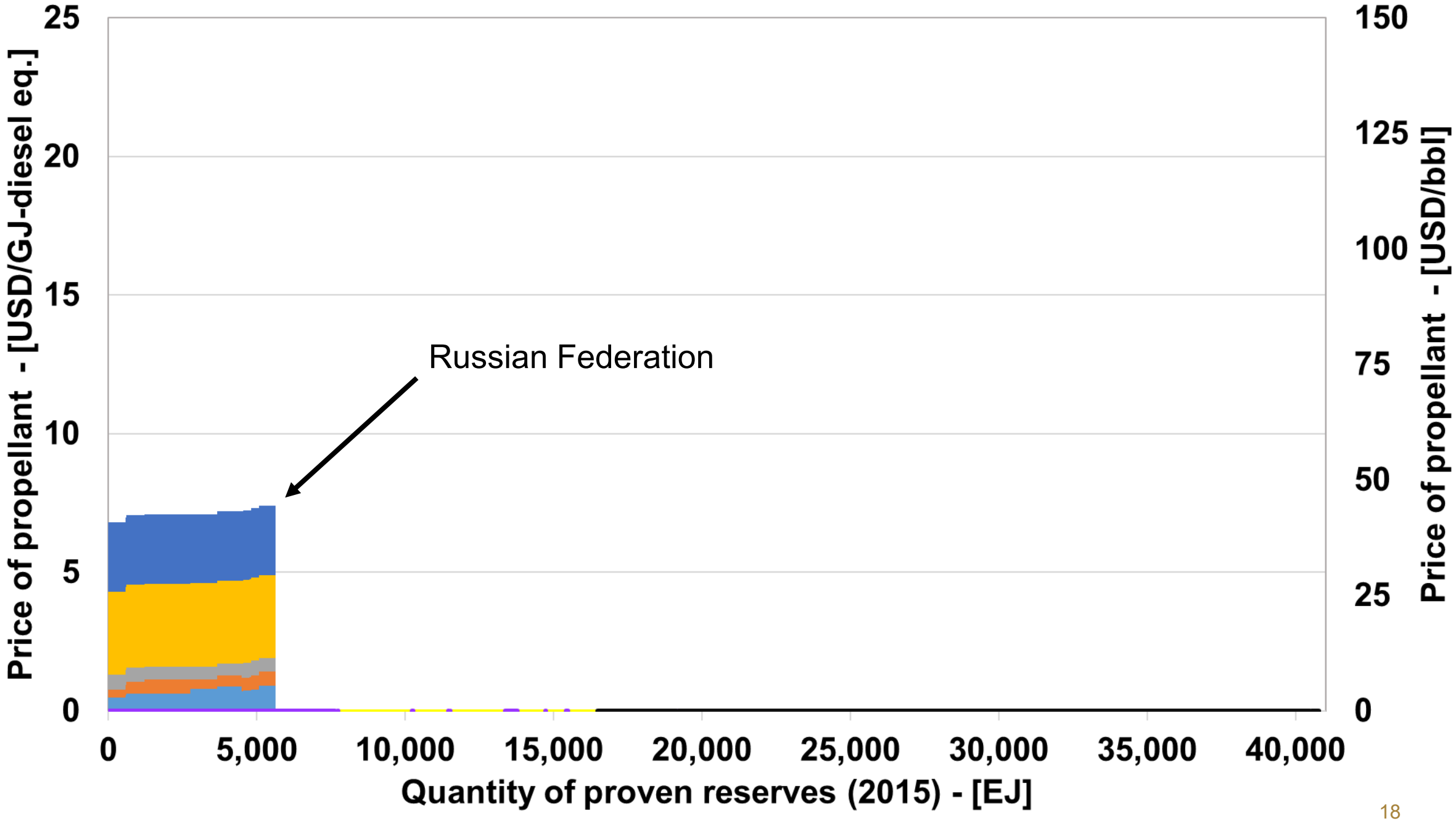

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
150
125
100
75
50
25
0
Price of propellant - [USD/bbl]
Syria, Argentina, Chile, Azerbaijan, and Turkey
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

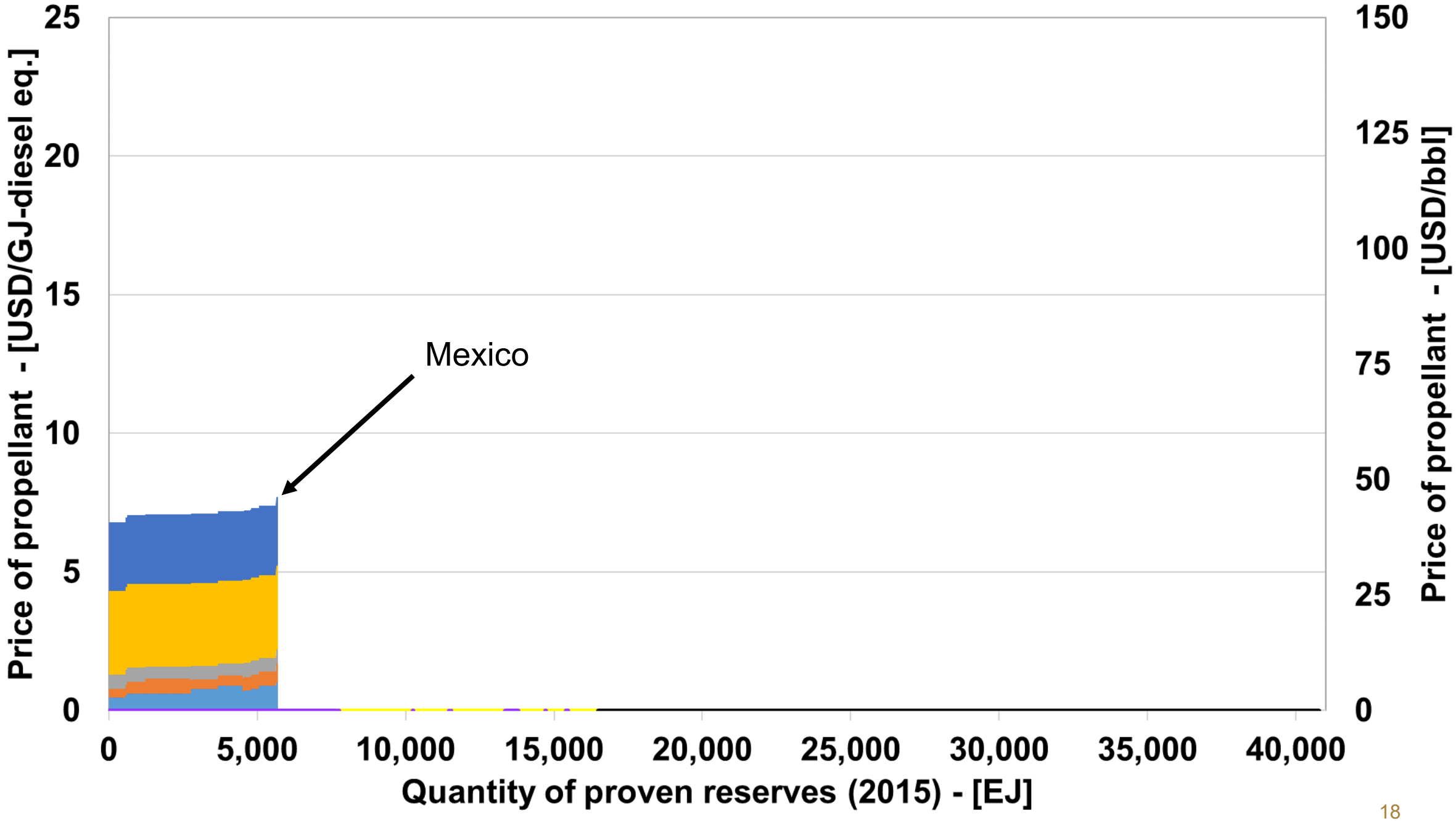

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Qatar
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

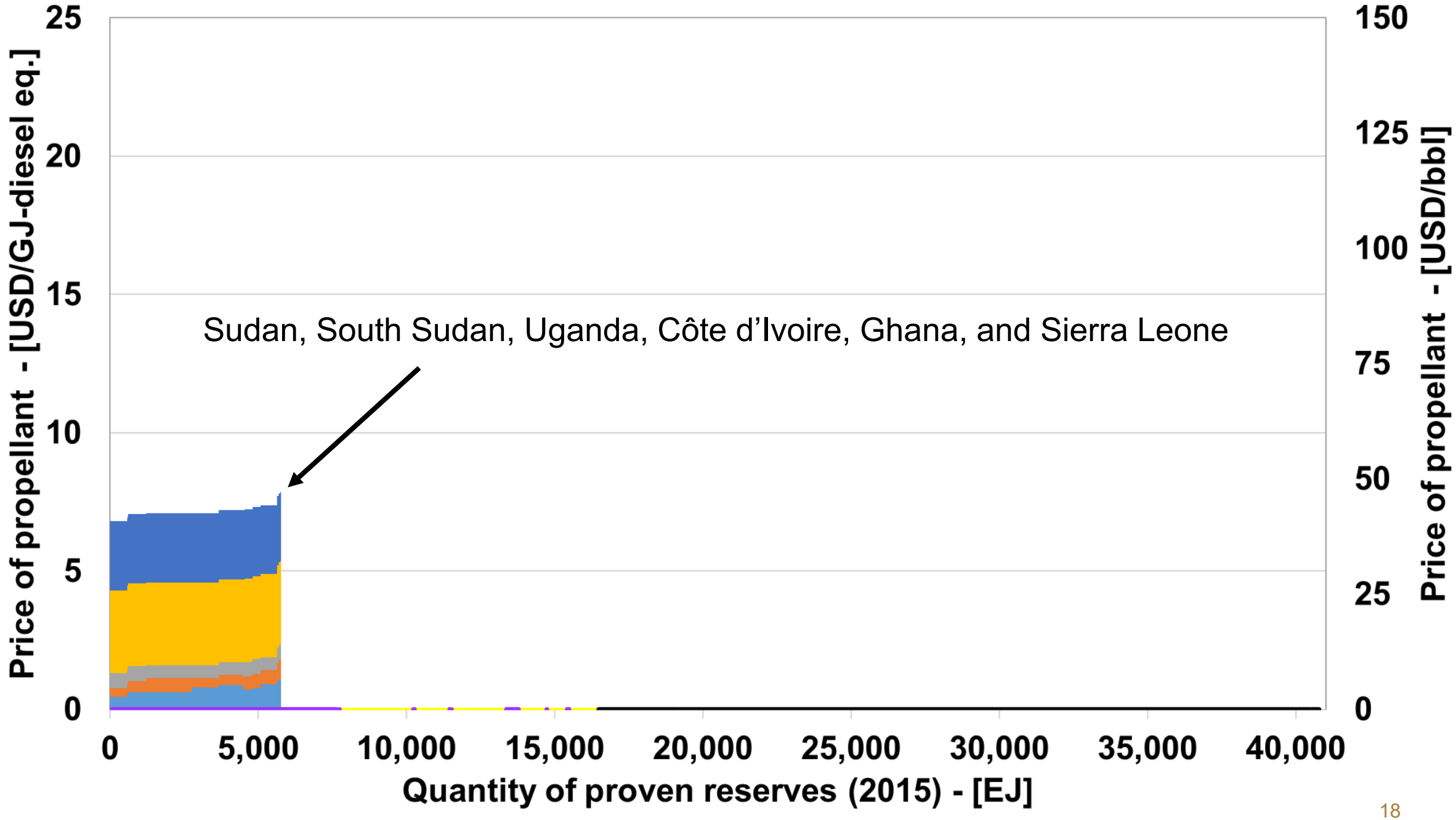

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Algeria and Tunisia
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

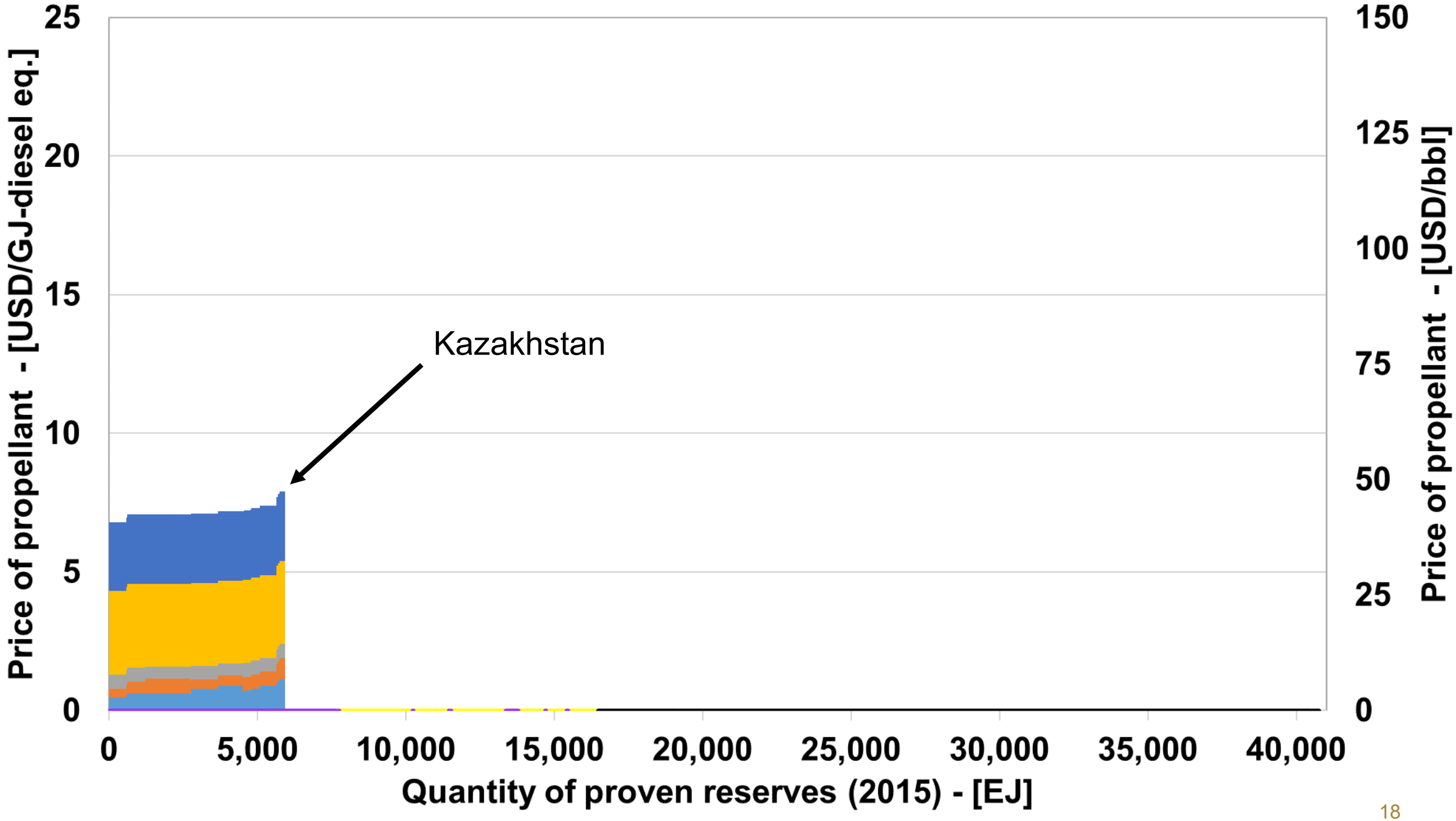

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
India and Pakistan
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

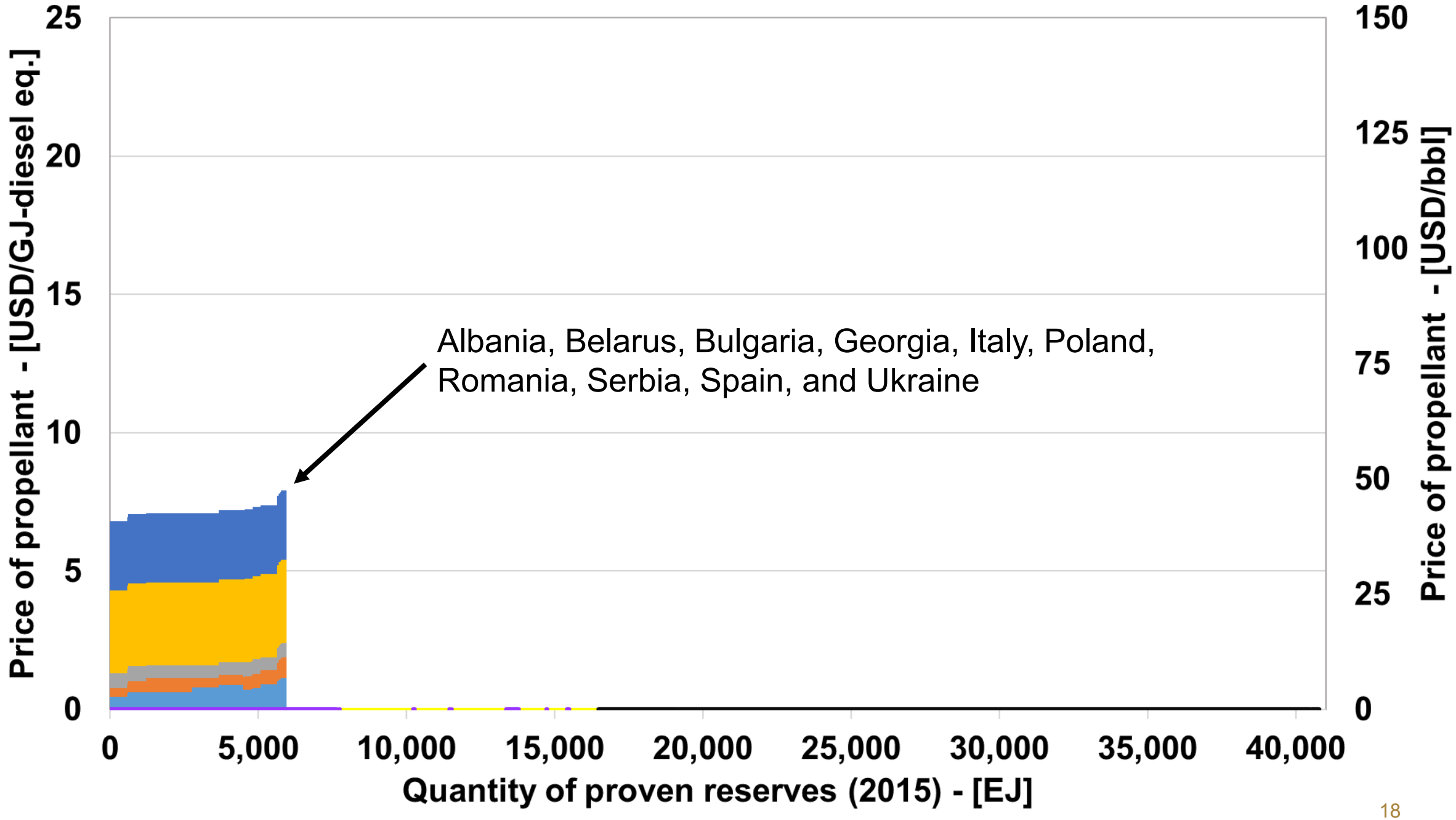

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Libya
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

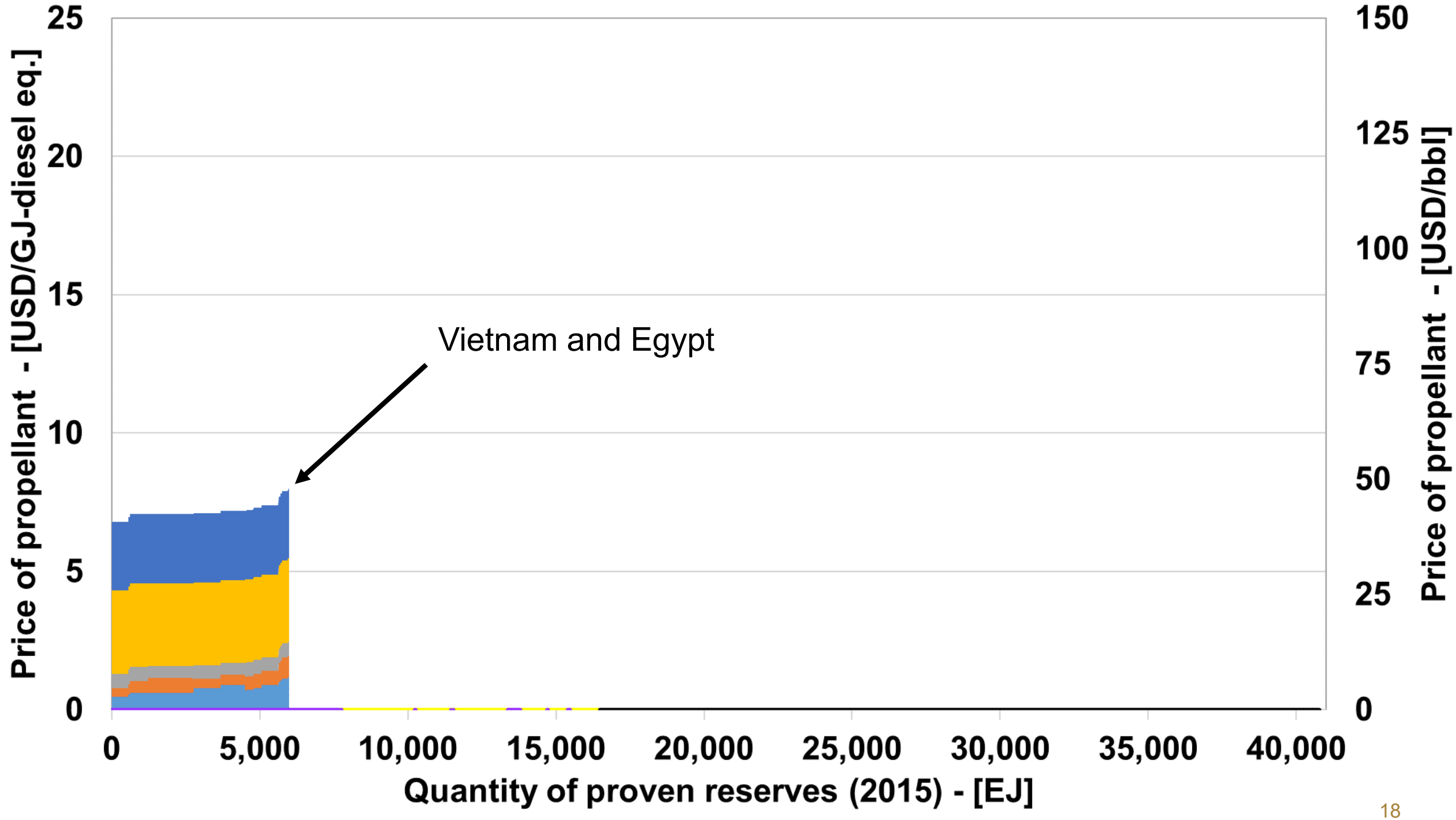

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Russian Federation
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

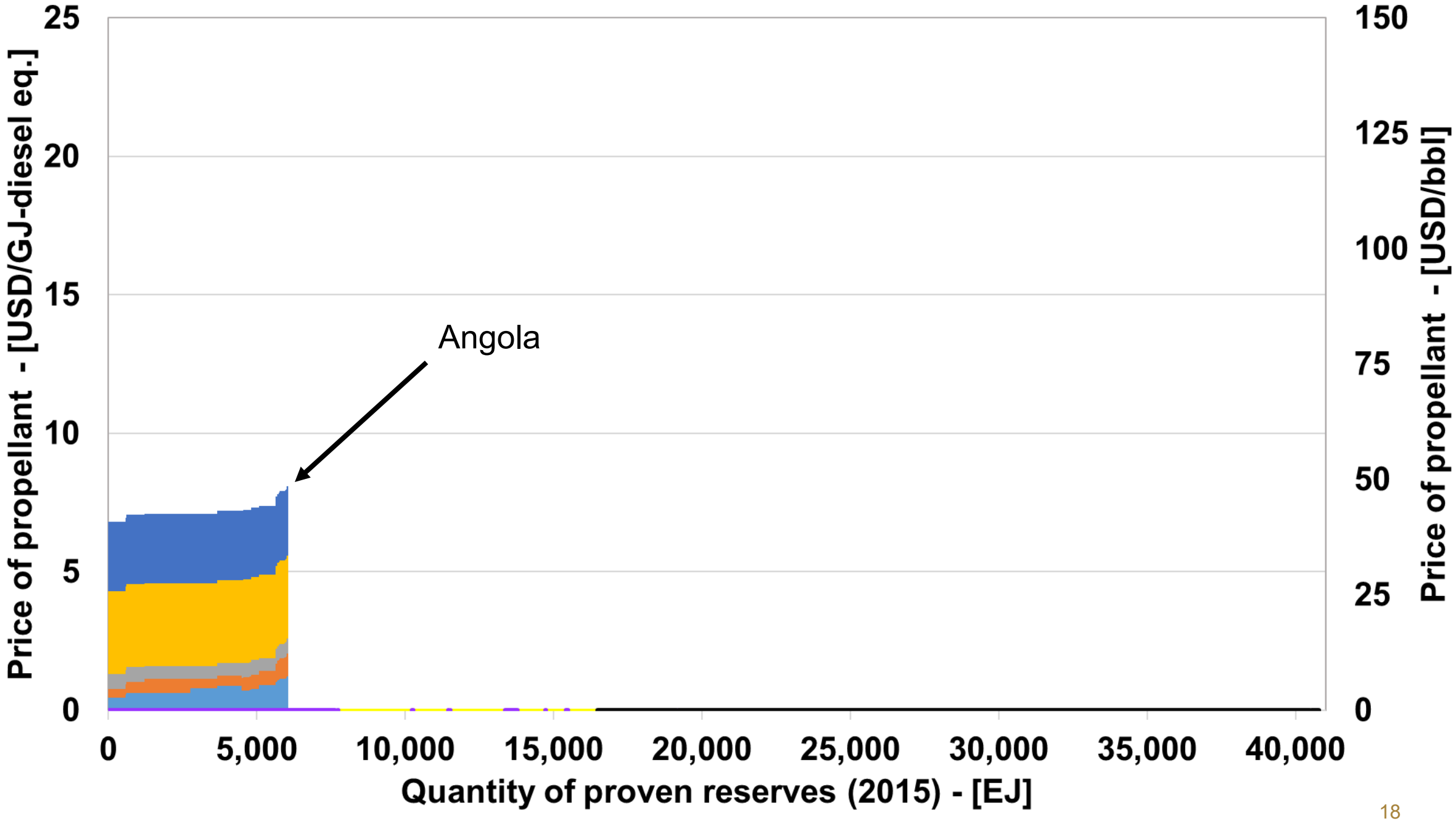

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Mexico
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

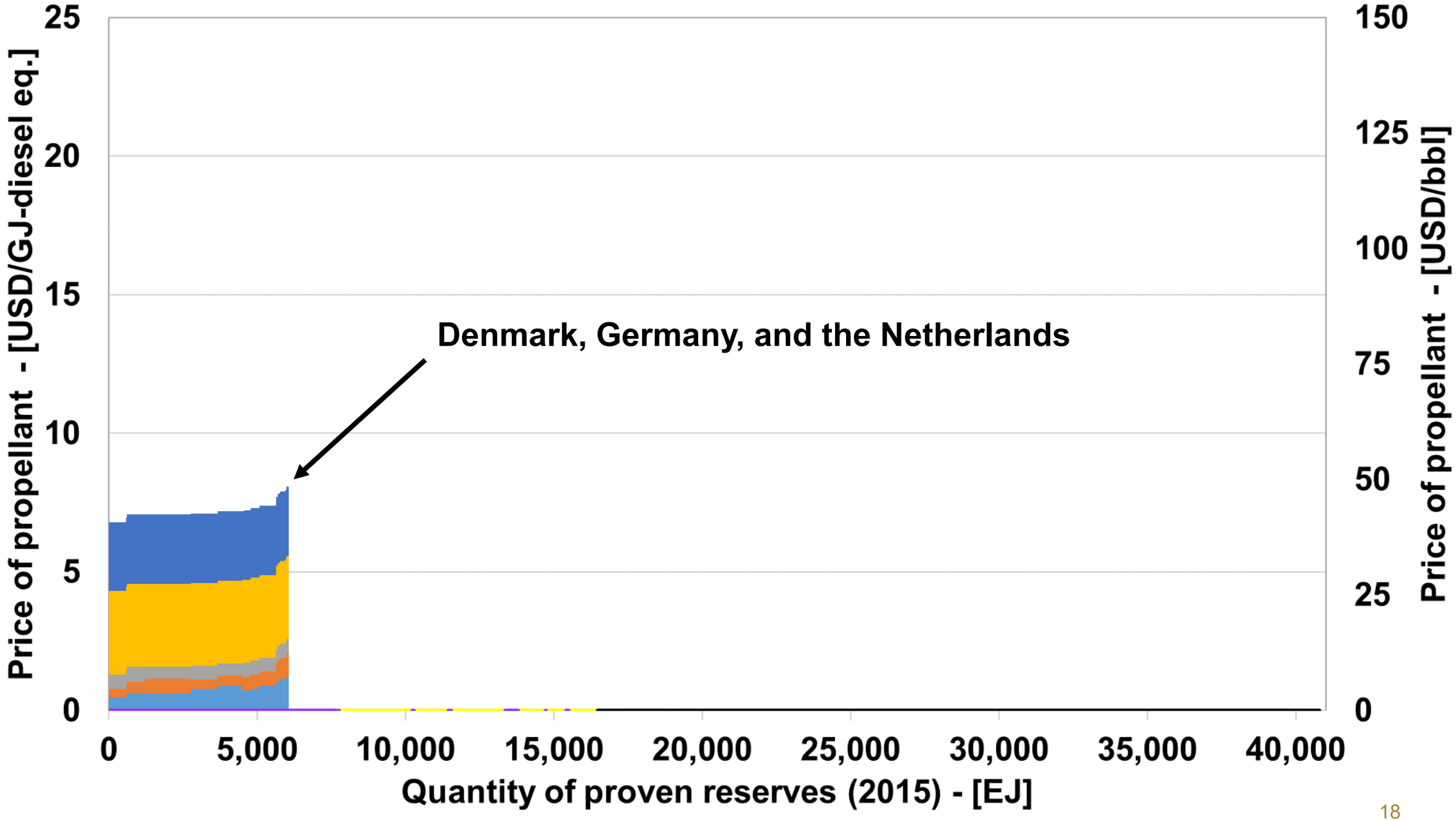

Sudan, South Sudan, Uganda, Côte d'Ivoire, Ghana, and Sierra Leone
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

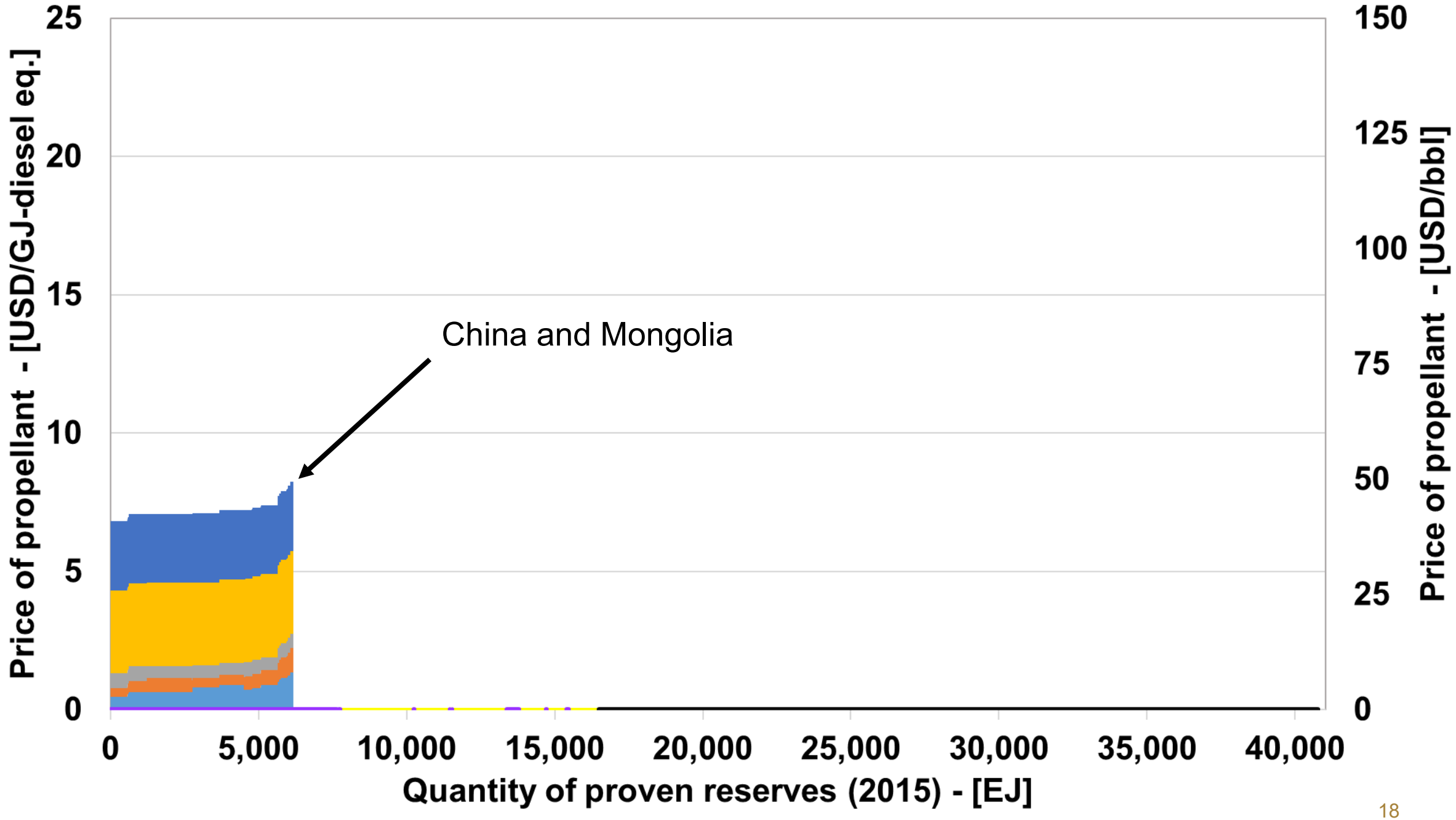

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Kazakhstan
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

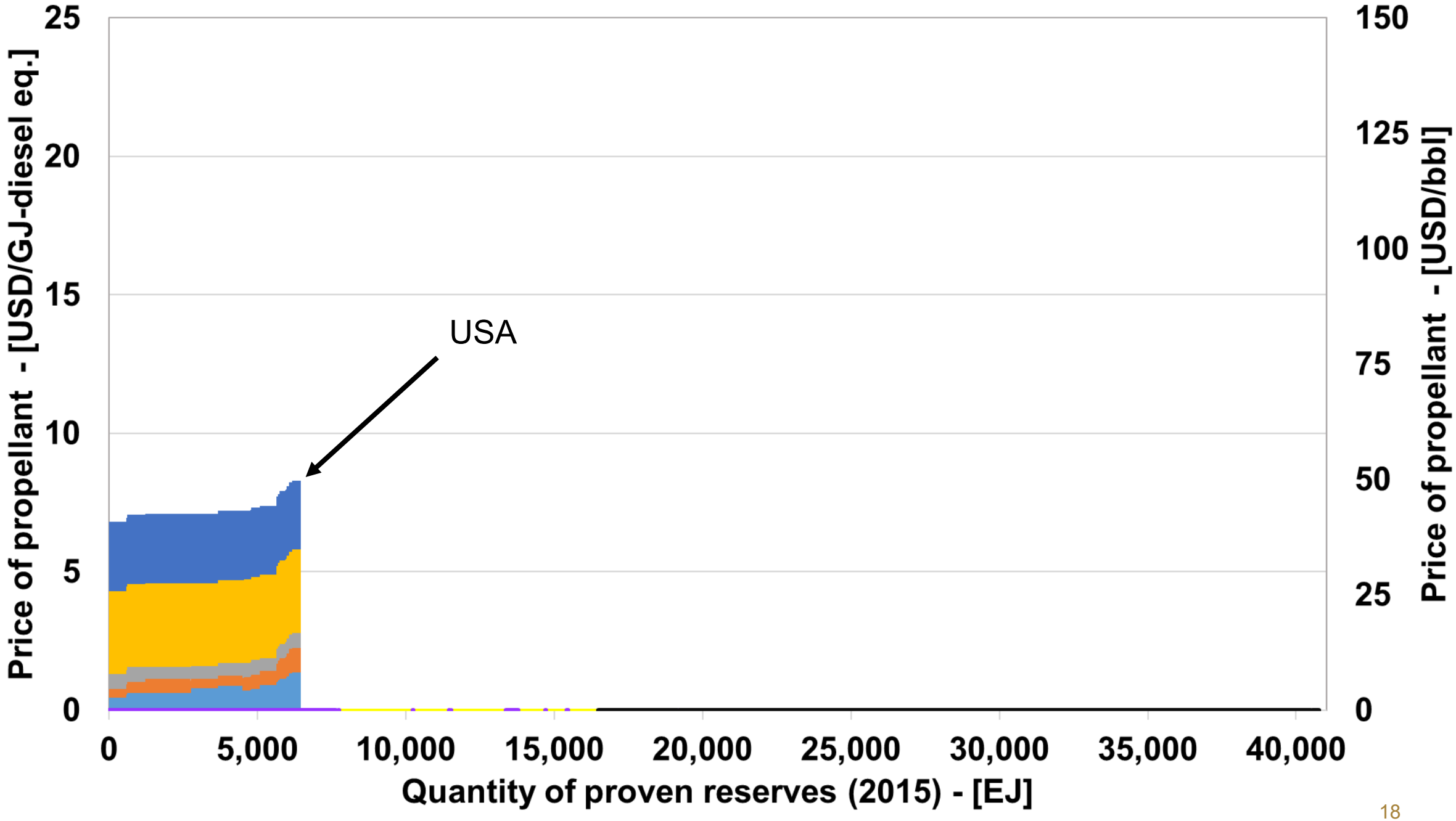

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Albania, Belarus, Bulgaria, Georgia, Italy, Poland,
Romania, Serbia, Spain, and Ukraine
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

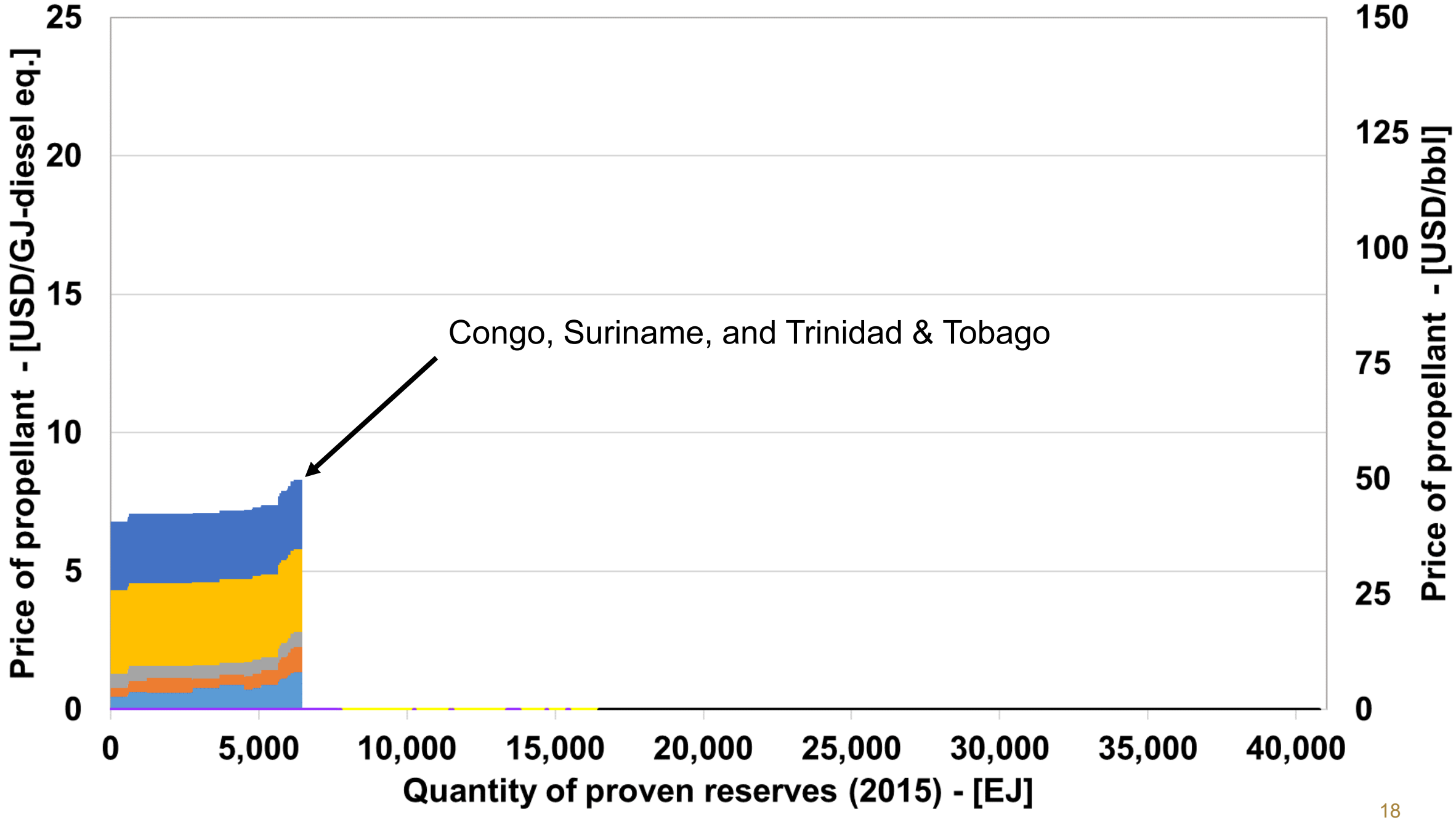

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Vietnam and Egypt
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

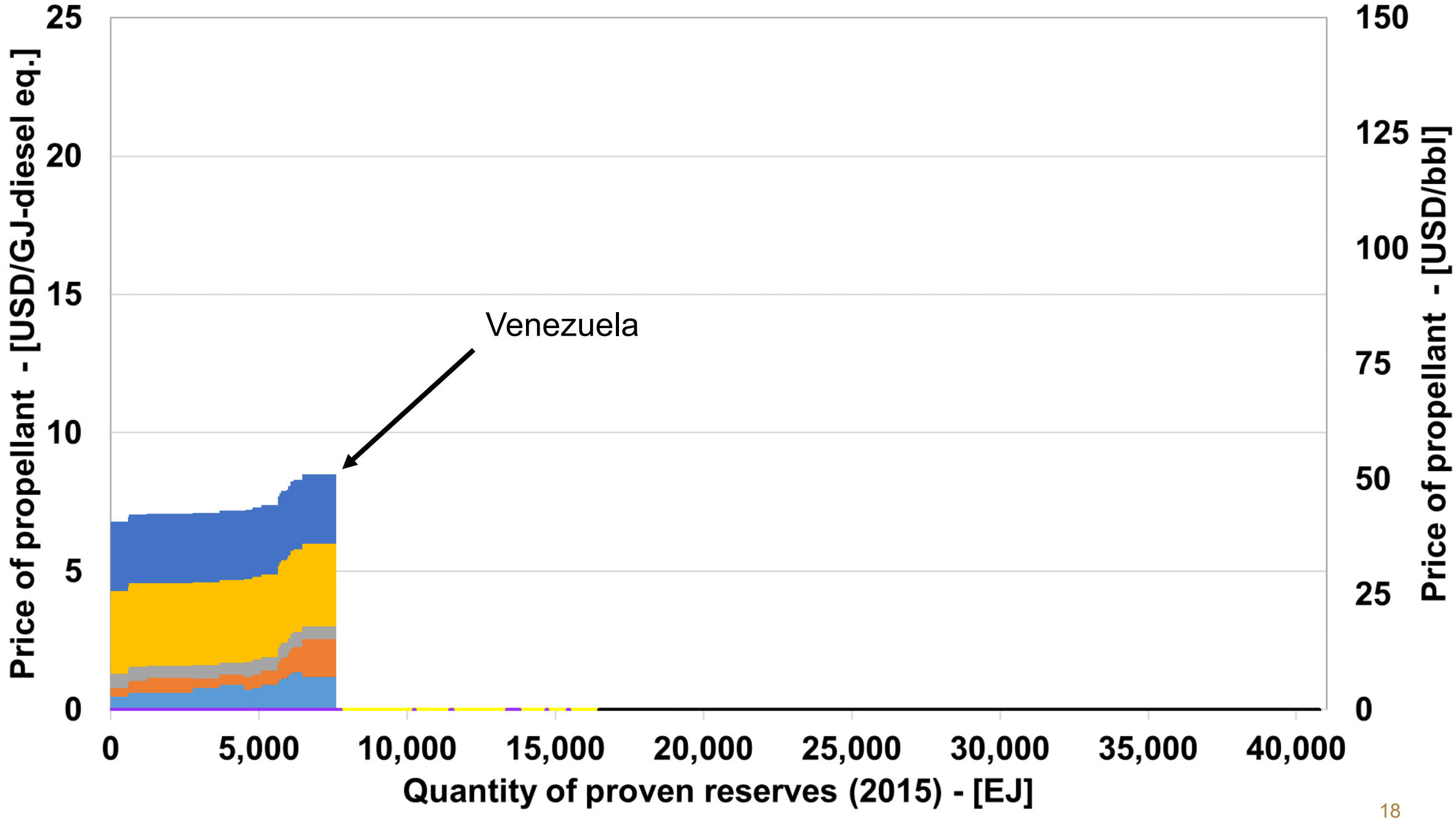

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Angola
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

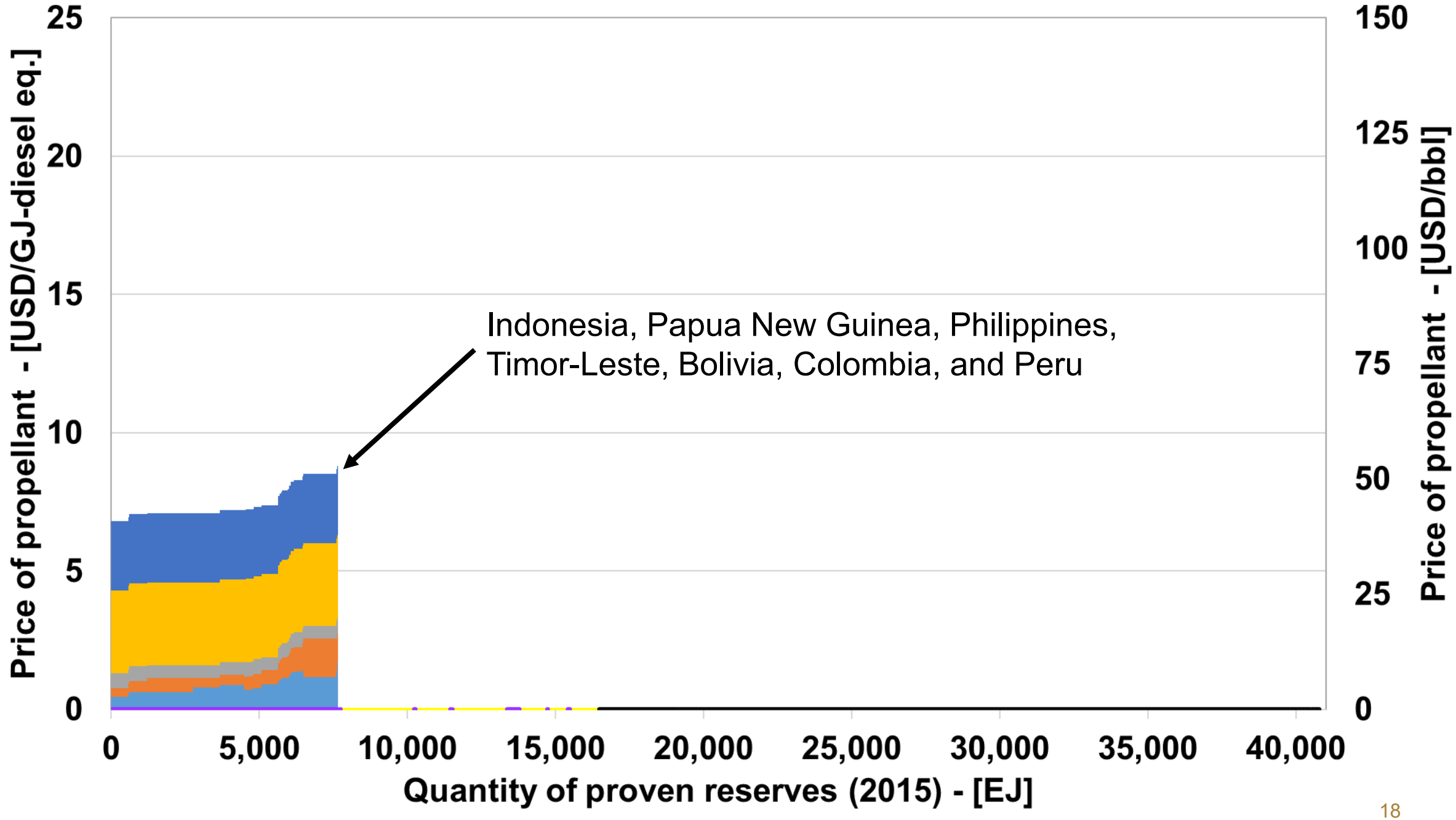

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Denmark, Germany, and the Netherlands
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

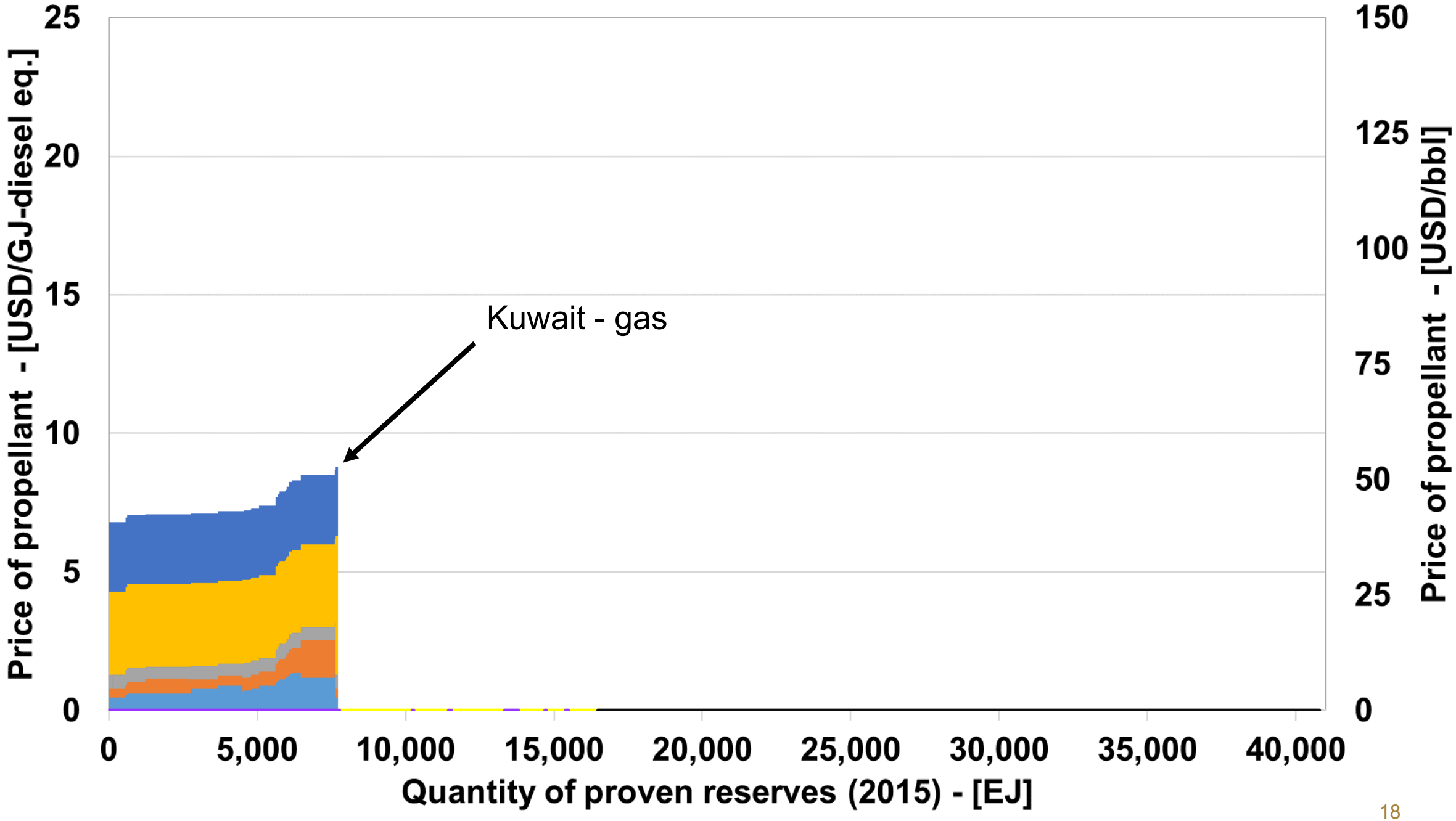

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
China and Mongolia
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

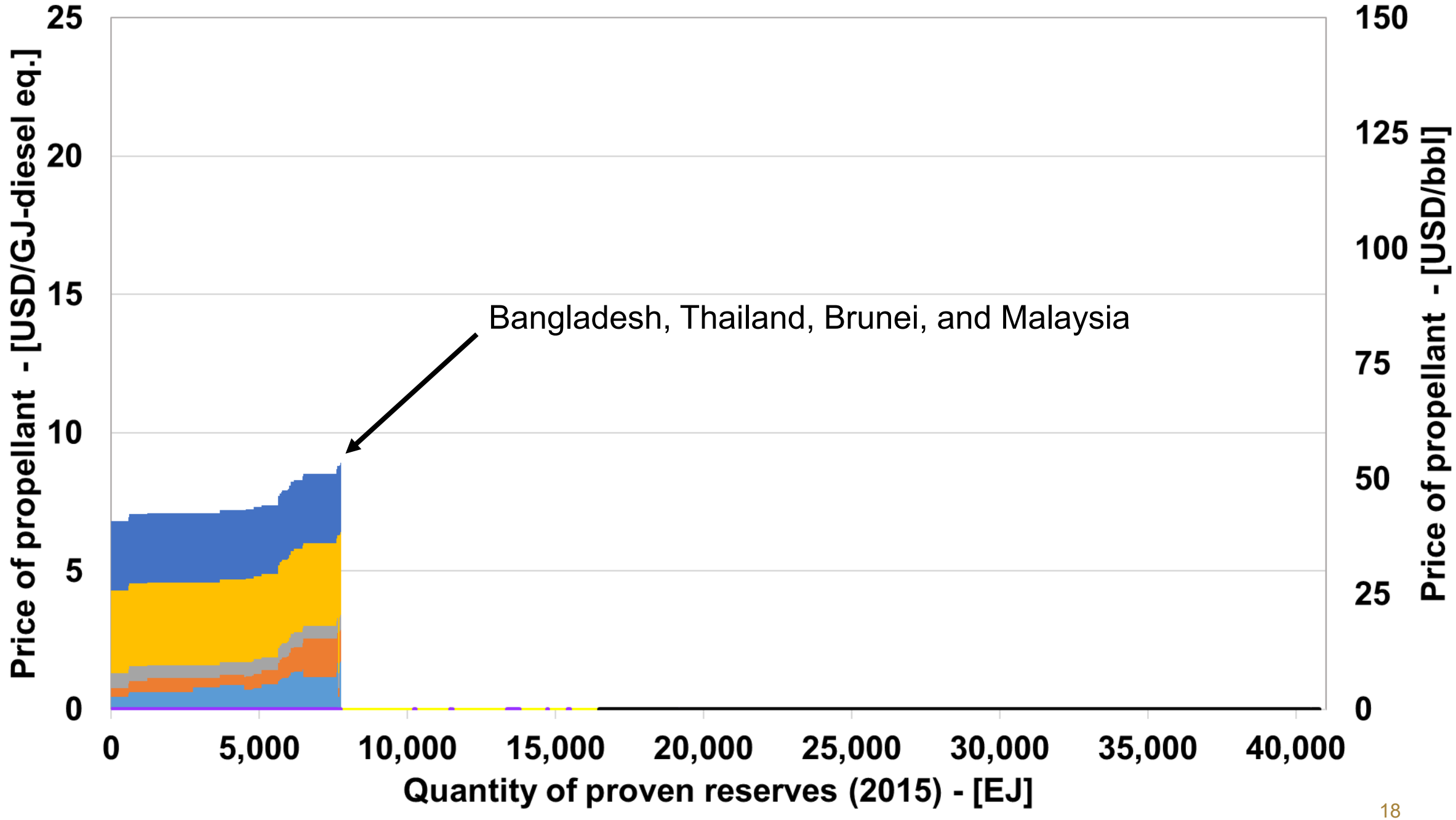

25
20
15
10
5
0
Price of propellant - [USD/GJ-diesel eq.]
150
125
100
75
50
25
0
Price of propellant - [USD/bbl]
USA
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

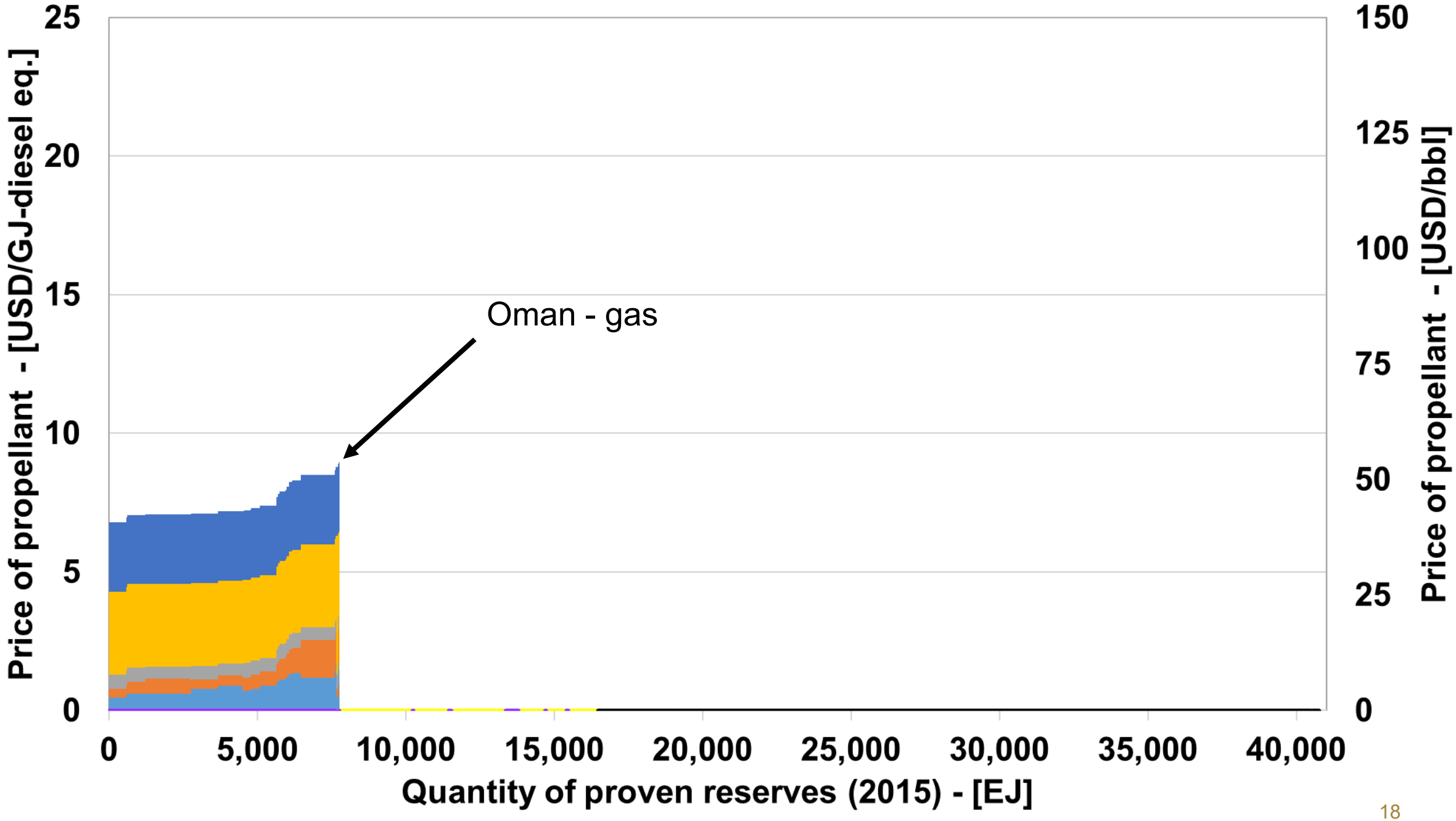

Congo, Suriname, and Trinidad & Tobago
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

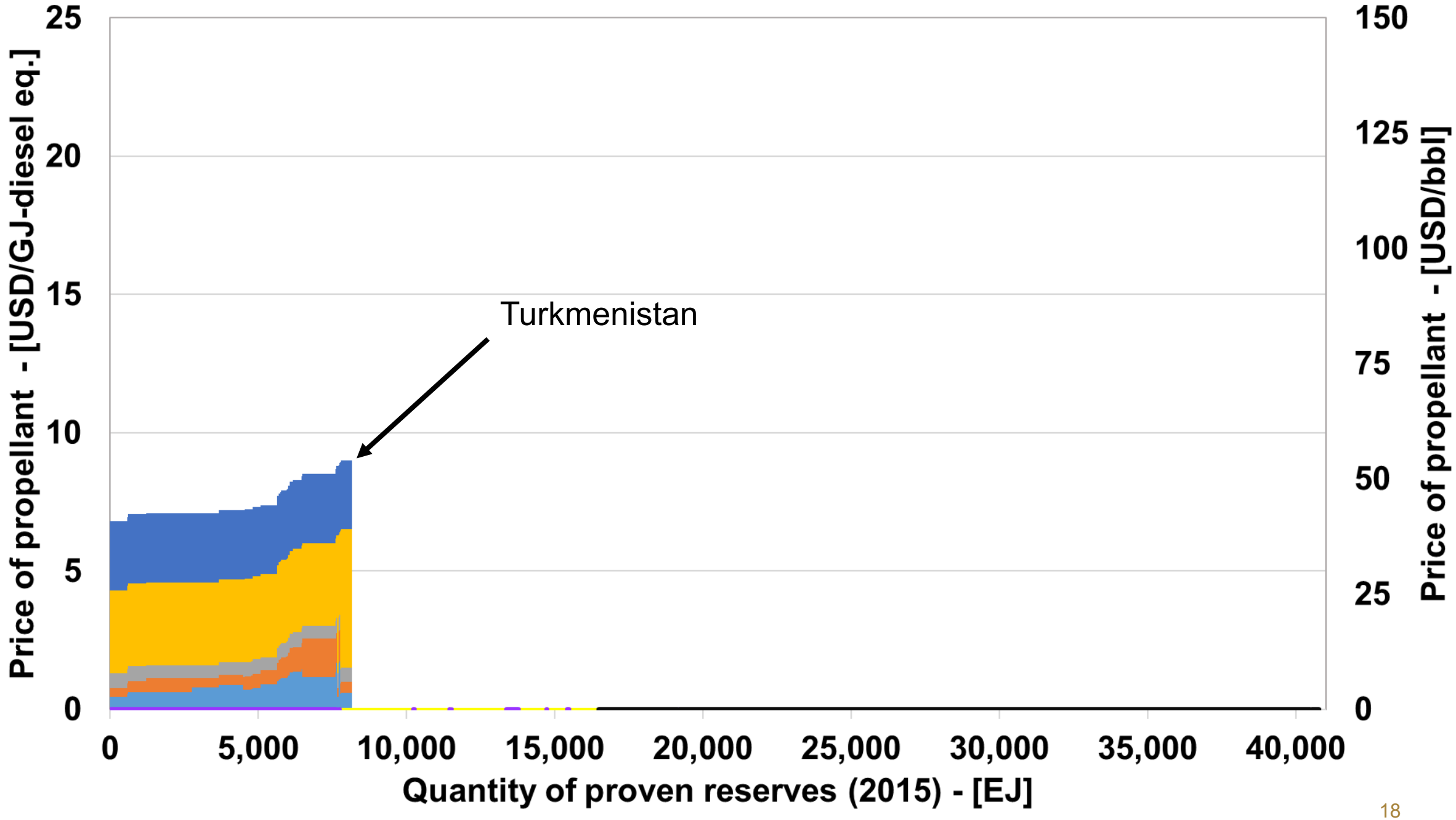

Venezuela
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

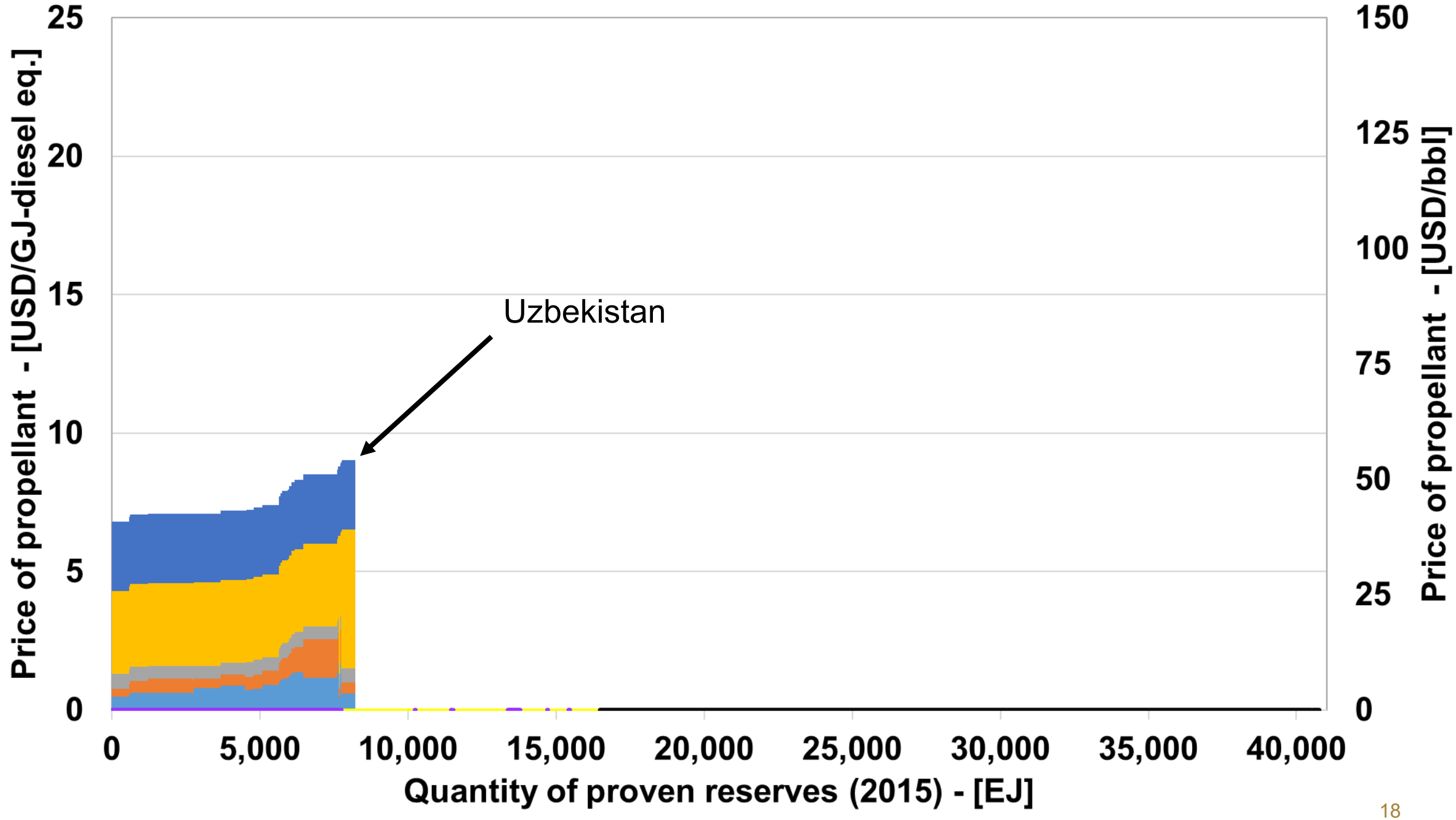

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Indonesia, Papua New Guinea, Philippines,
Timor-Leste, Bolivia, Colombia, and Peru
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

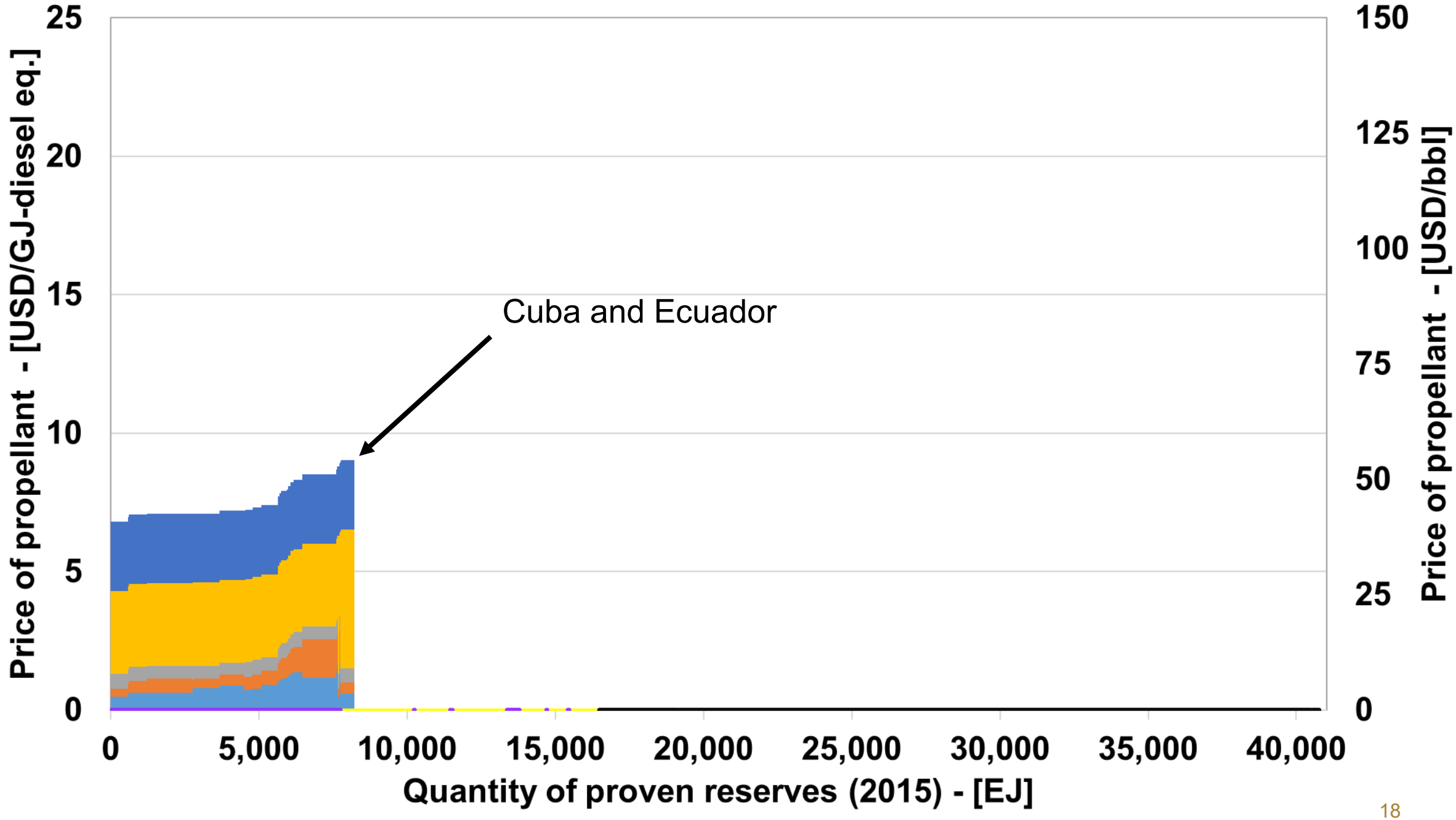

Kuwait - gas
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

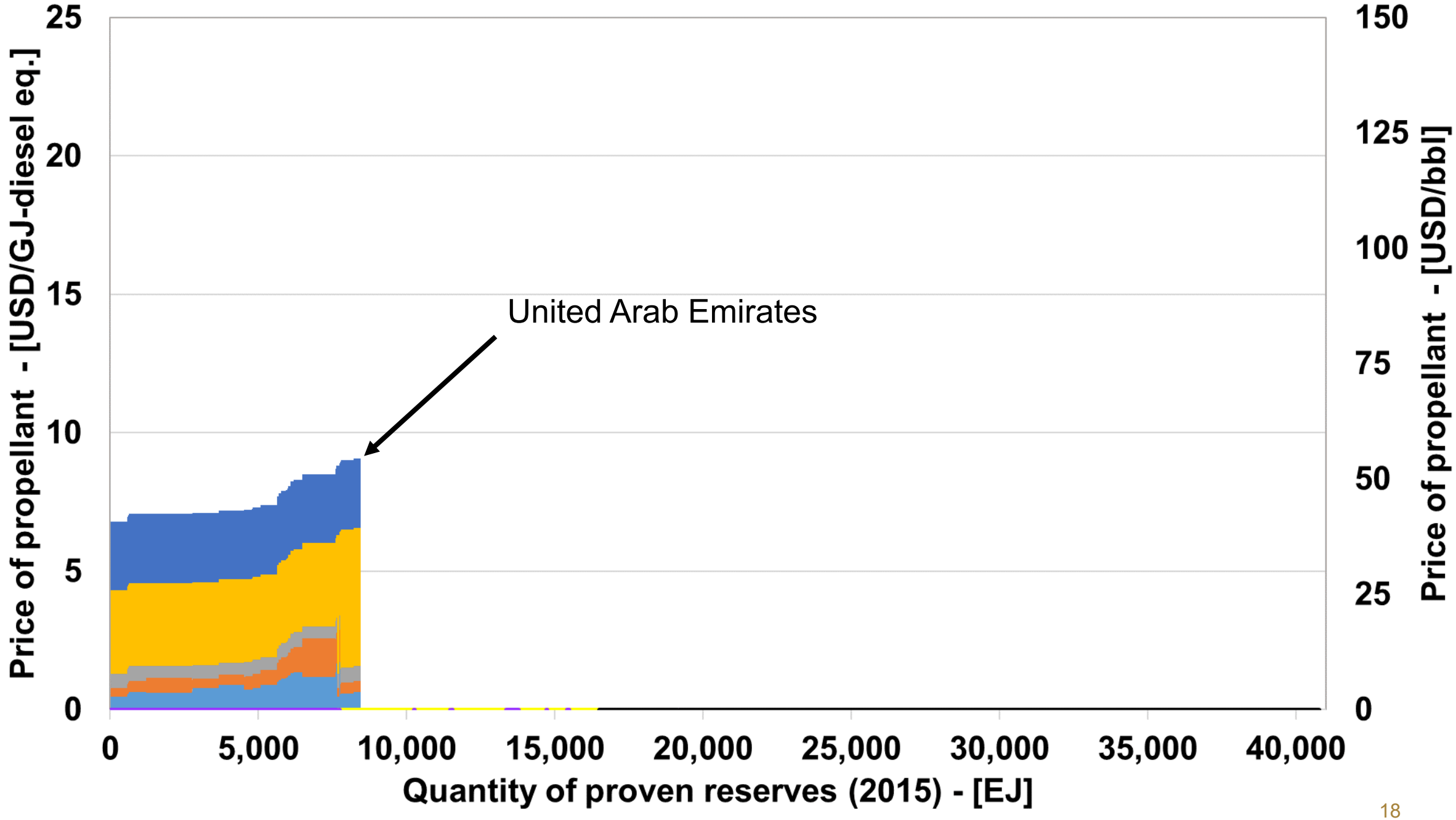

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Bangladesh, Thailand, Brunei, and Malaysia
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

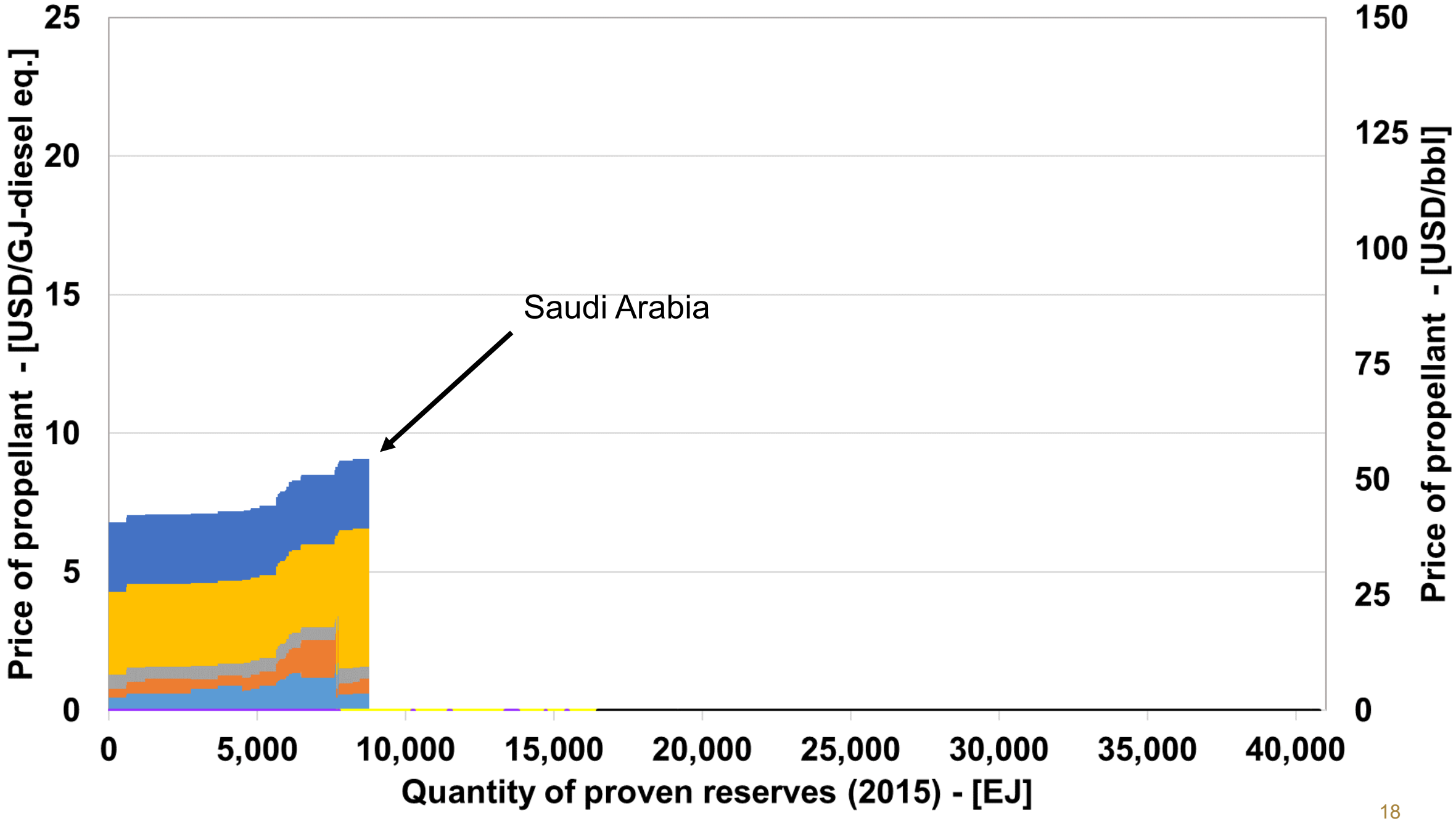

Oman - gas
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

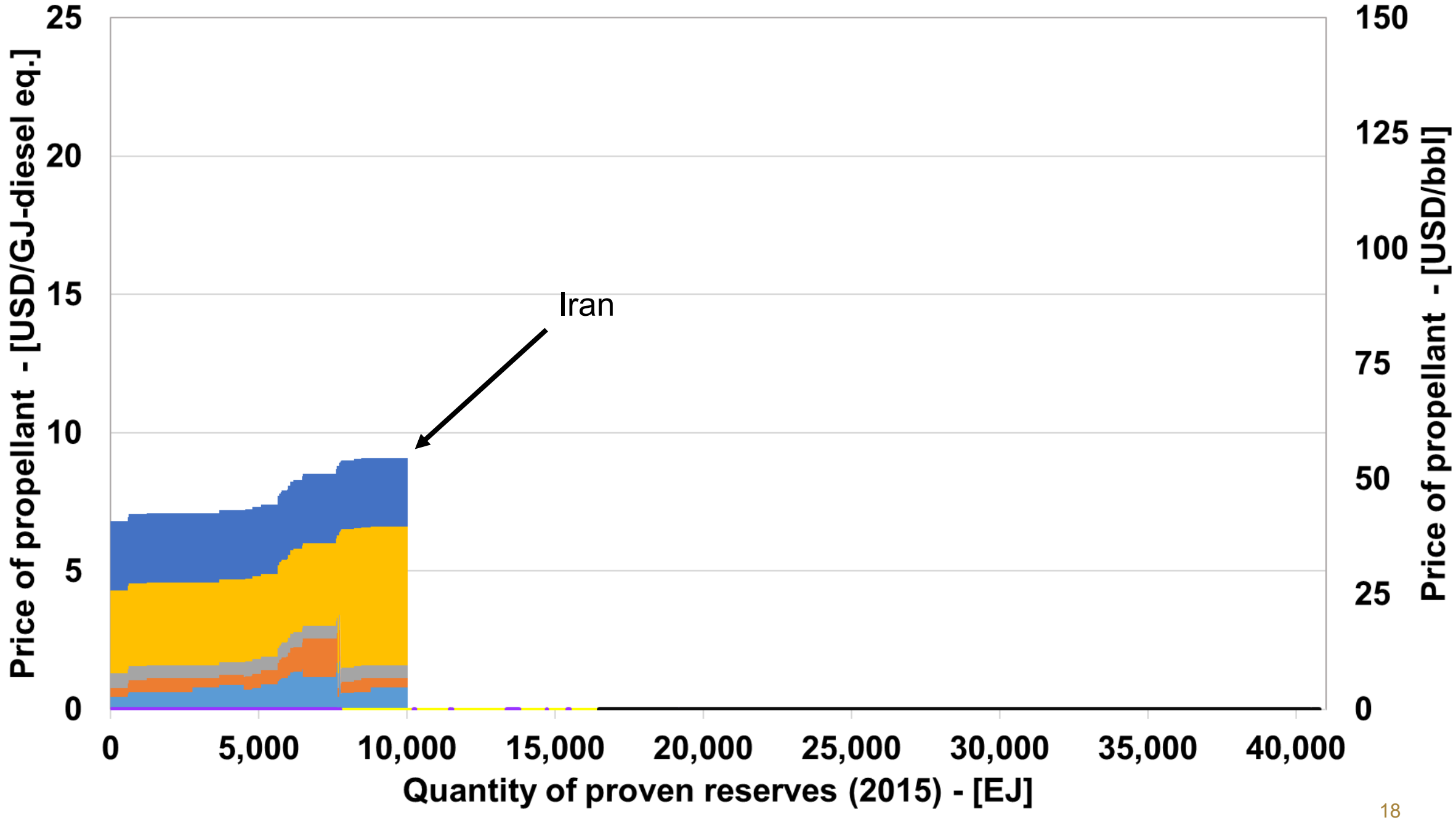

Turkmenistan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

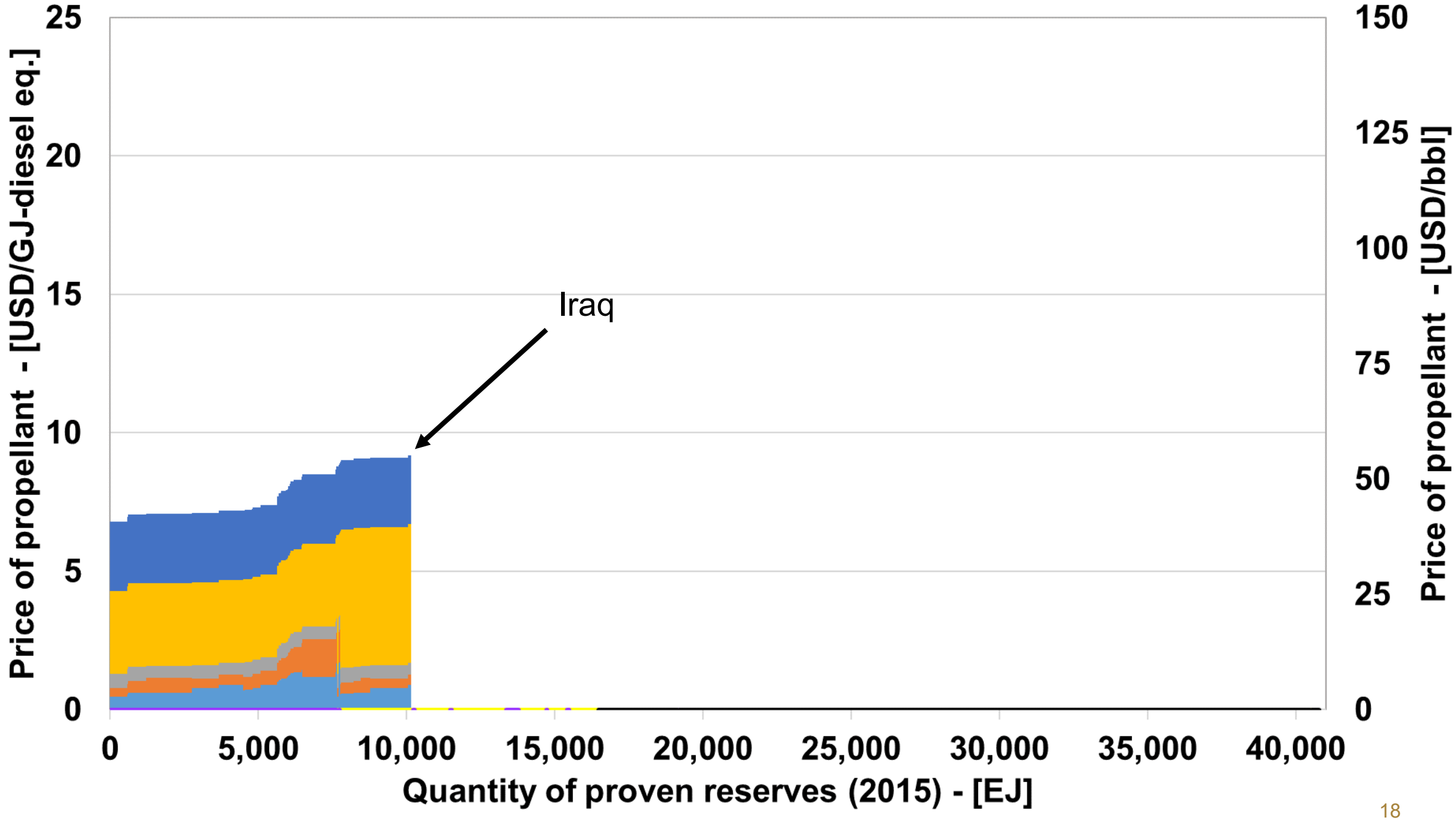

Uzbekistan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

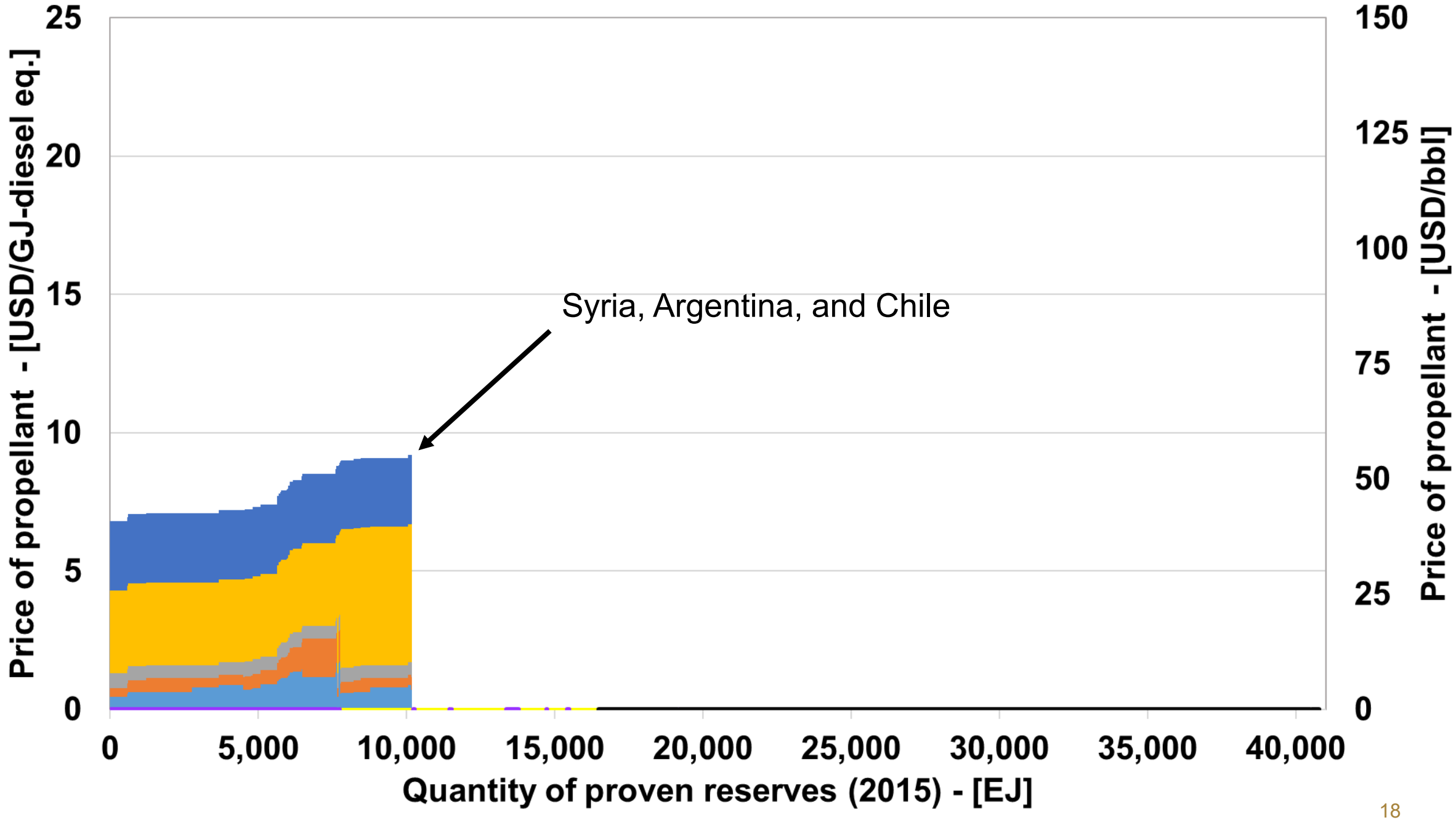

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Cuba and Ecuador
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

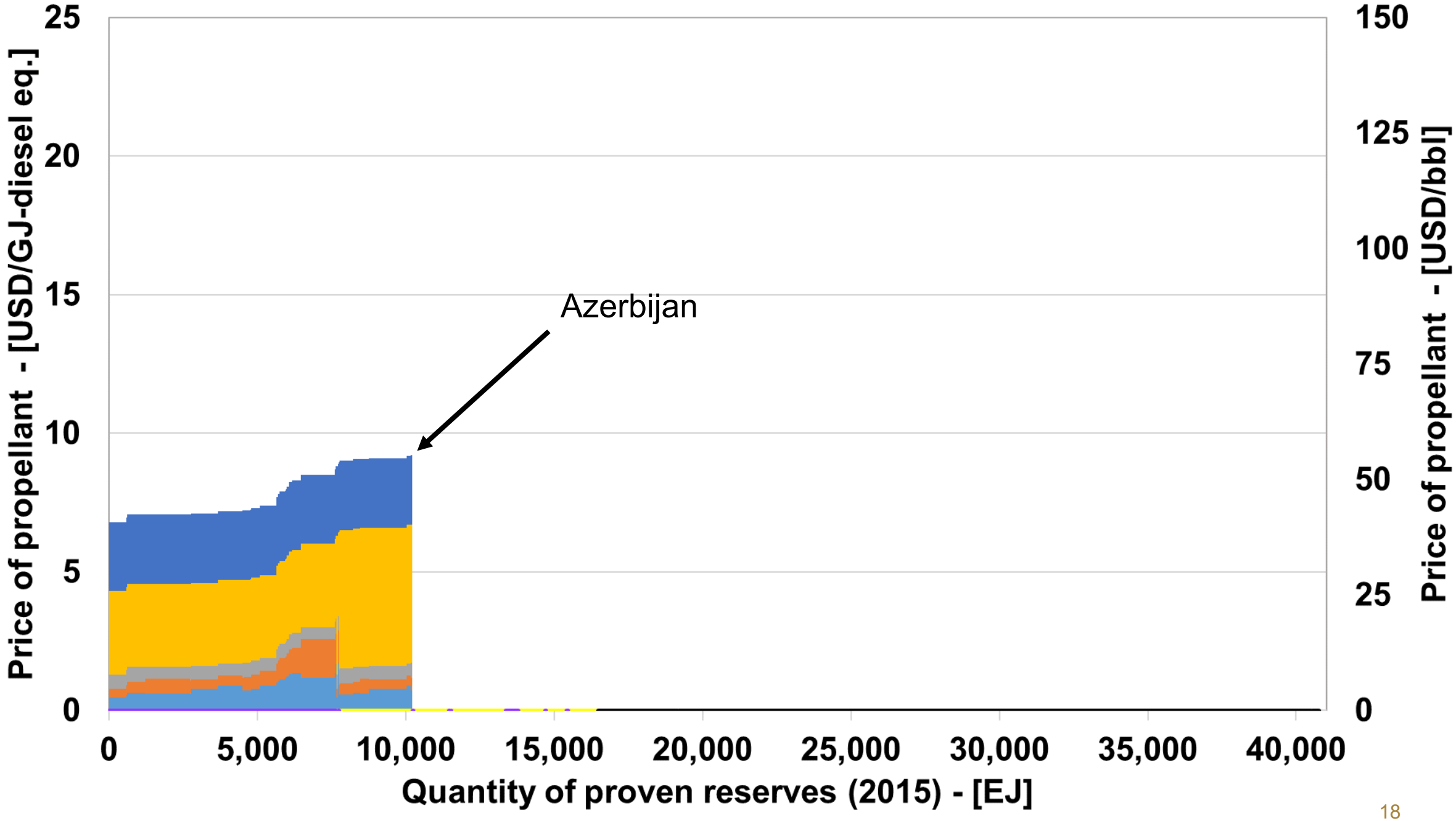

United Arab Emirates
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

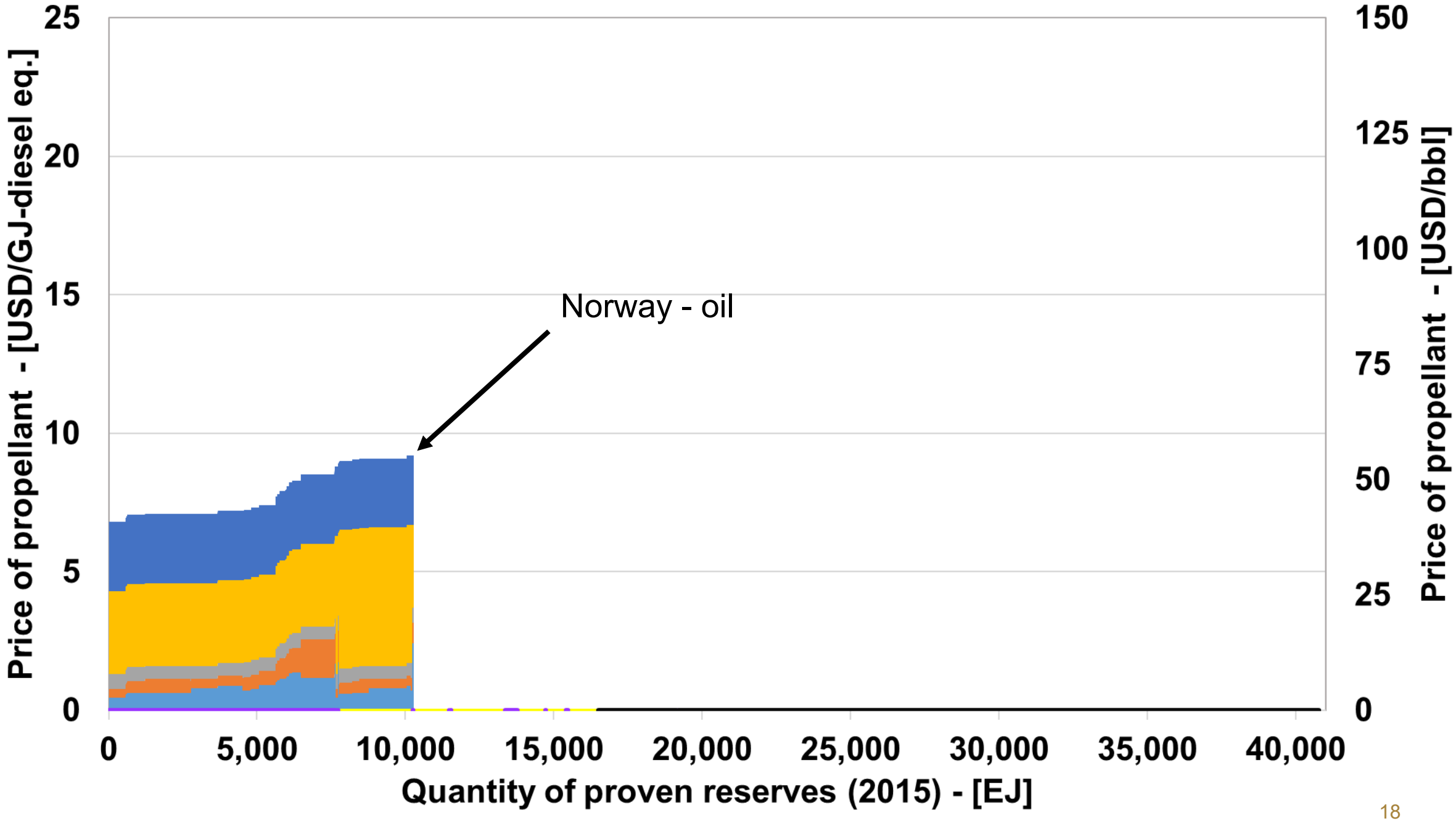

Saudi Arabia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

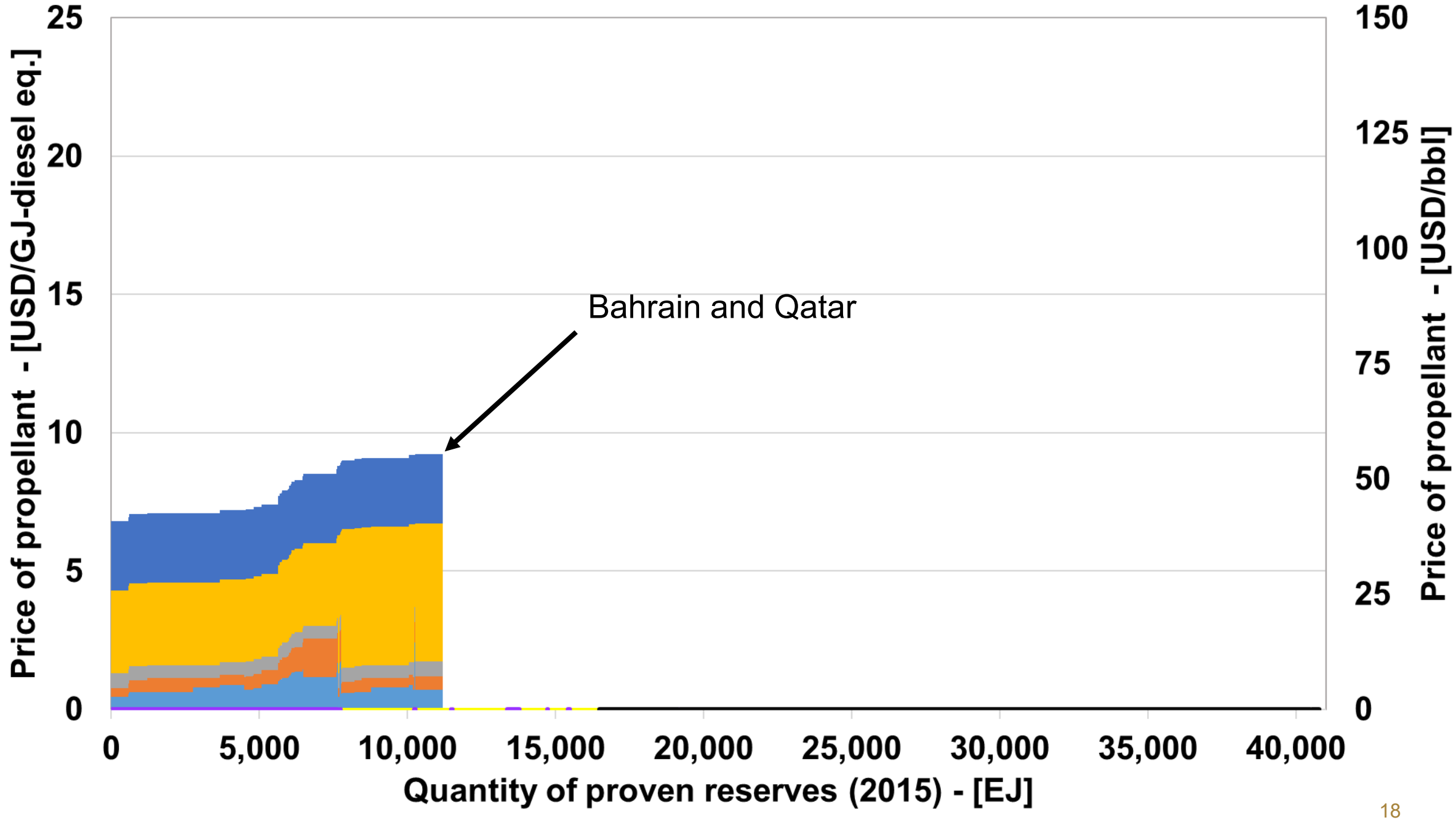

Iran
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

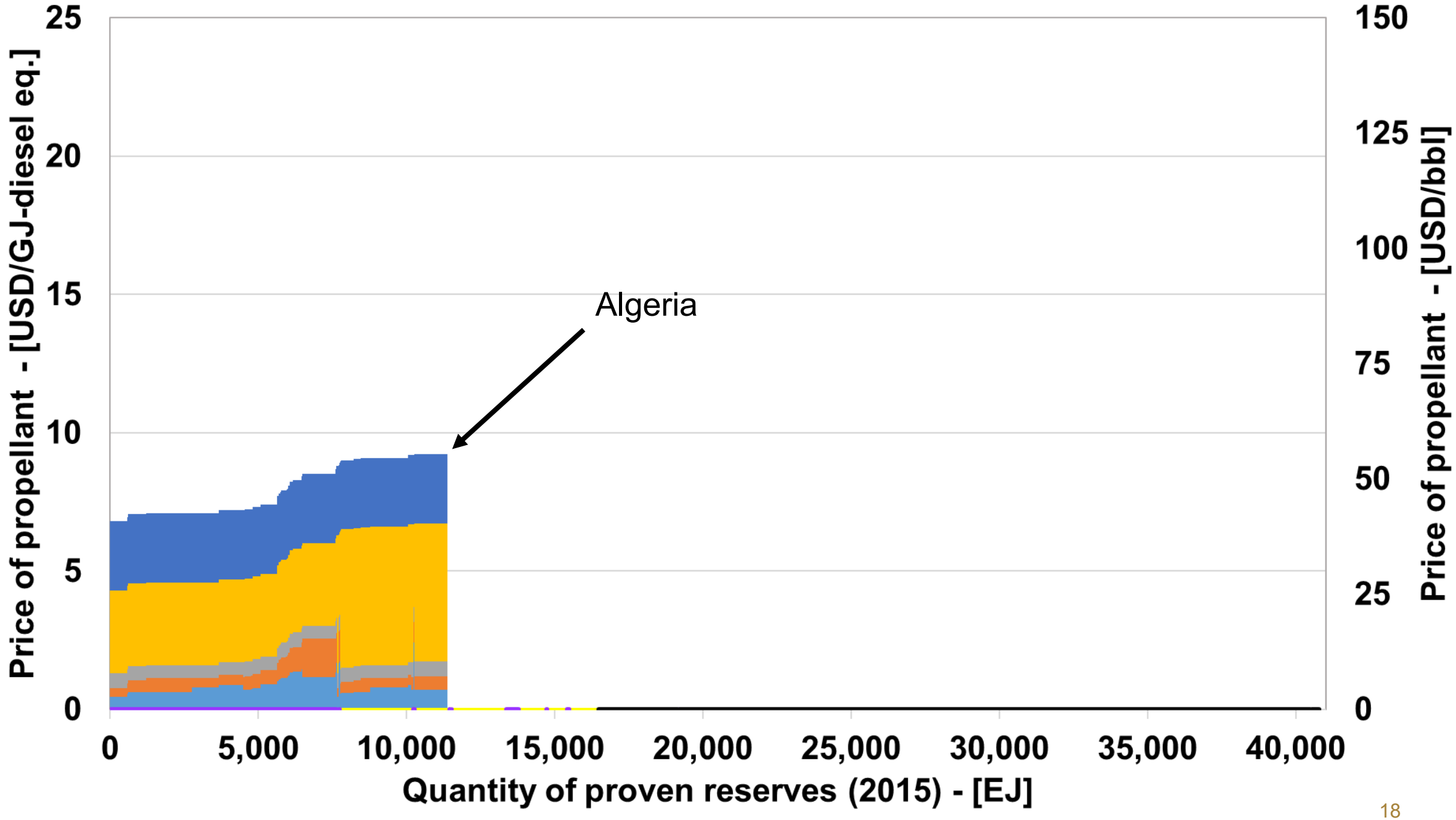

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Iraq
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

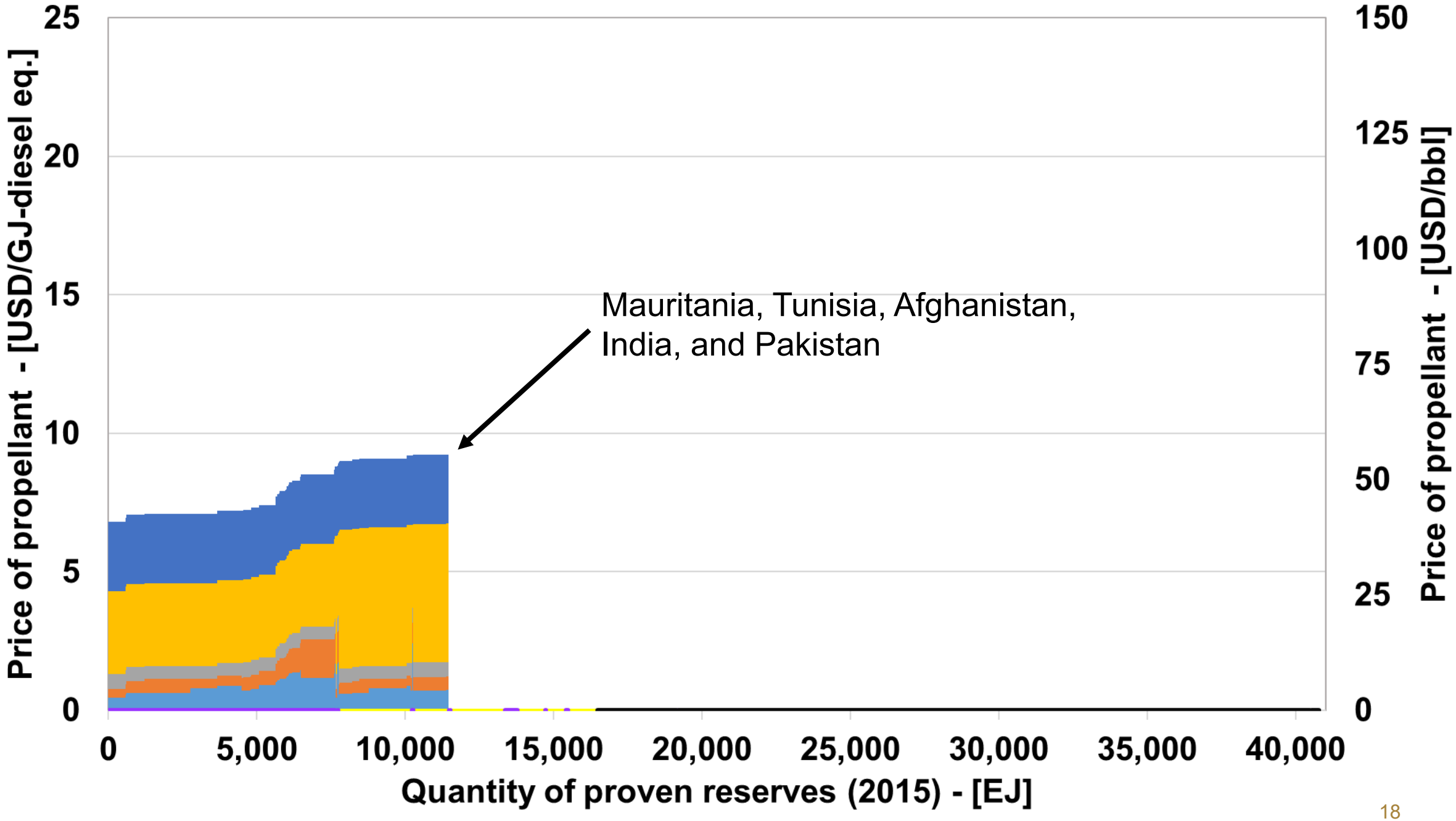

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Syria, Argentina, and Chile
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

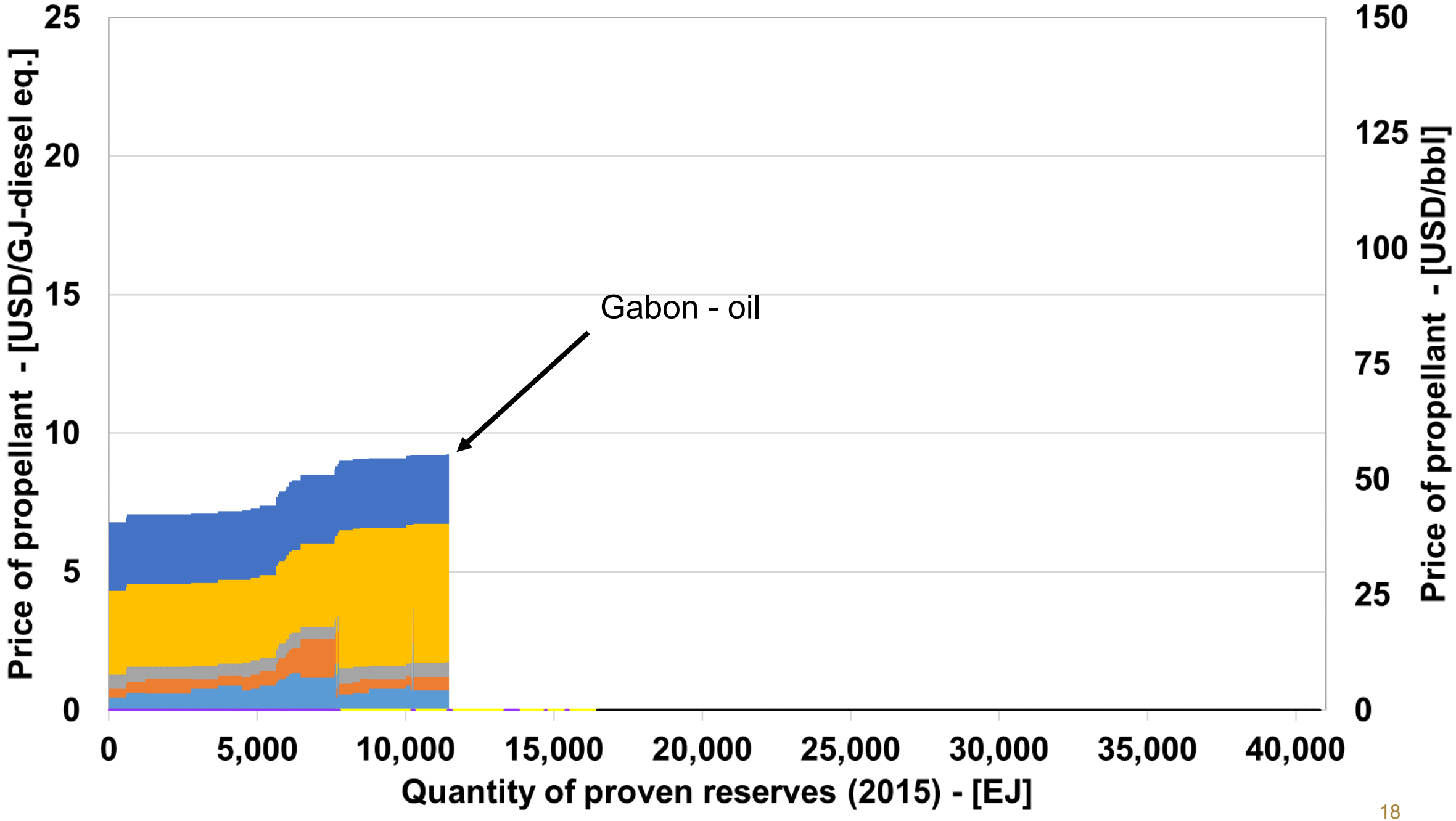

Azerbijan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

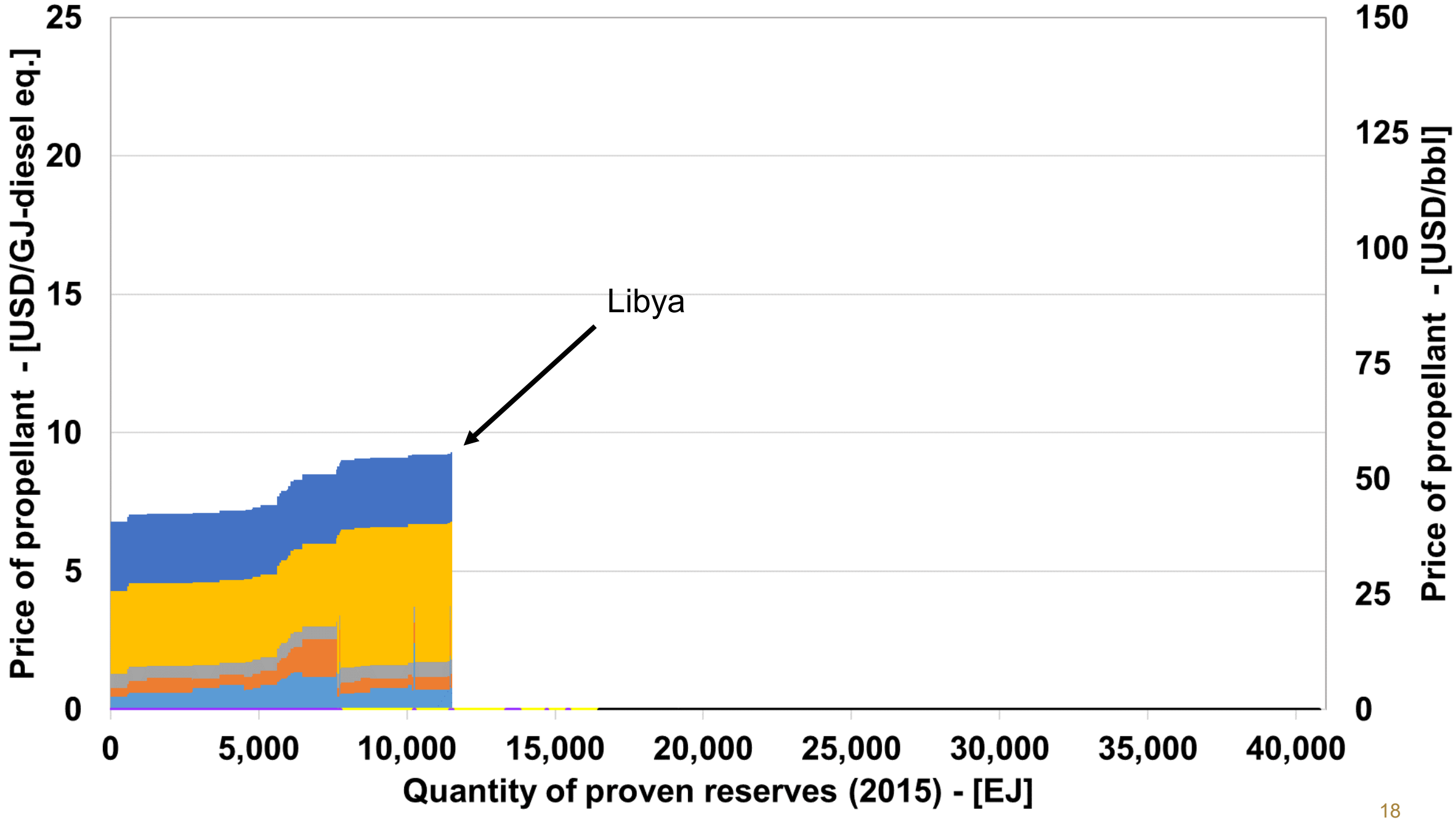

Norway - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

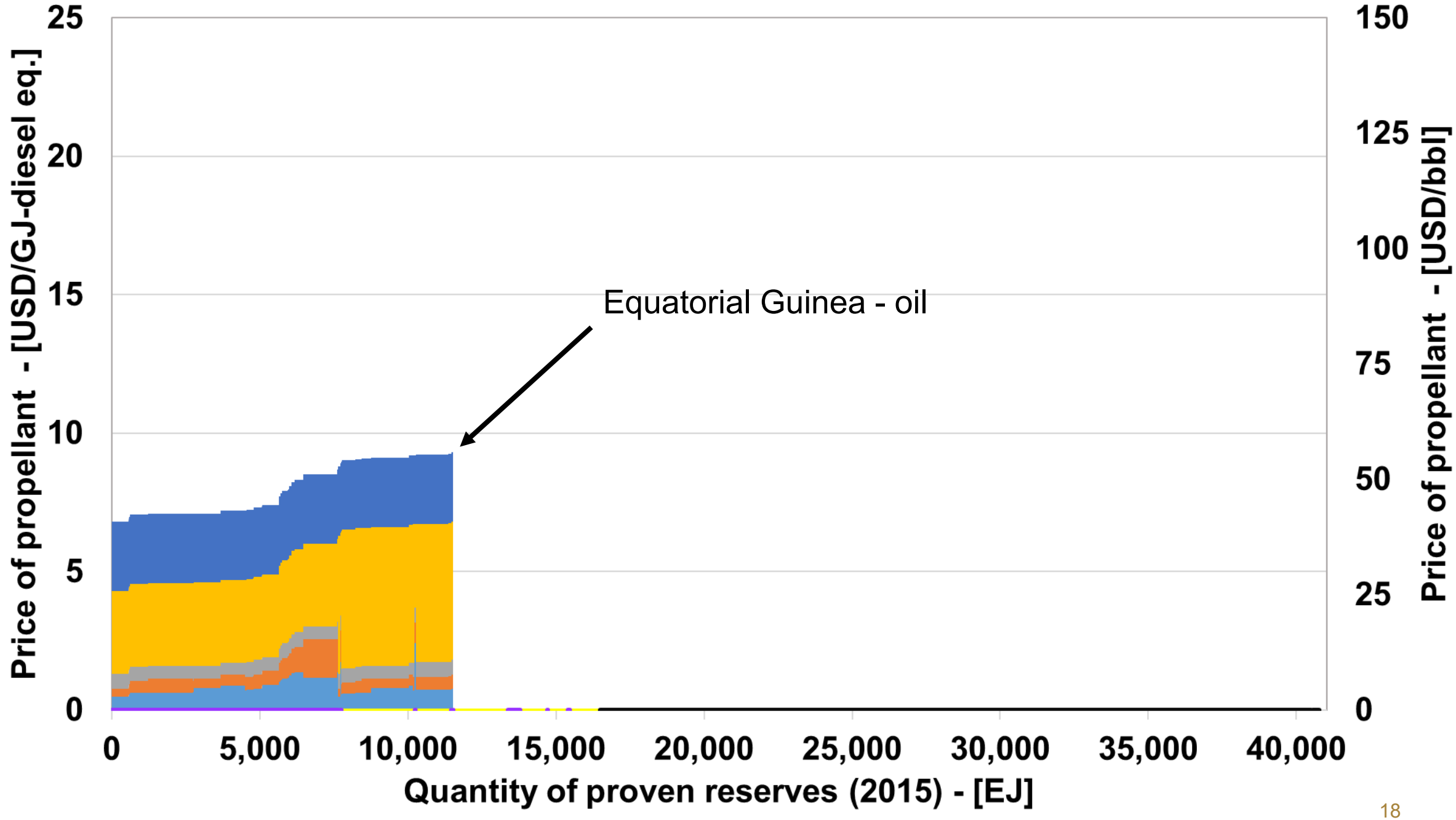

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Bahrain and Qatar
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

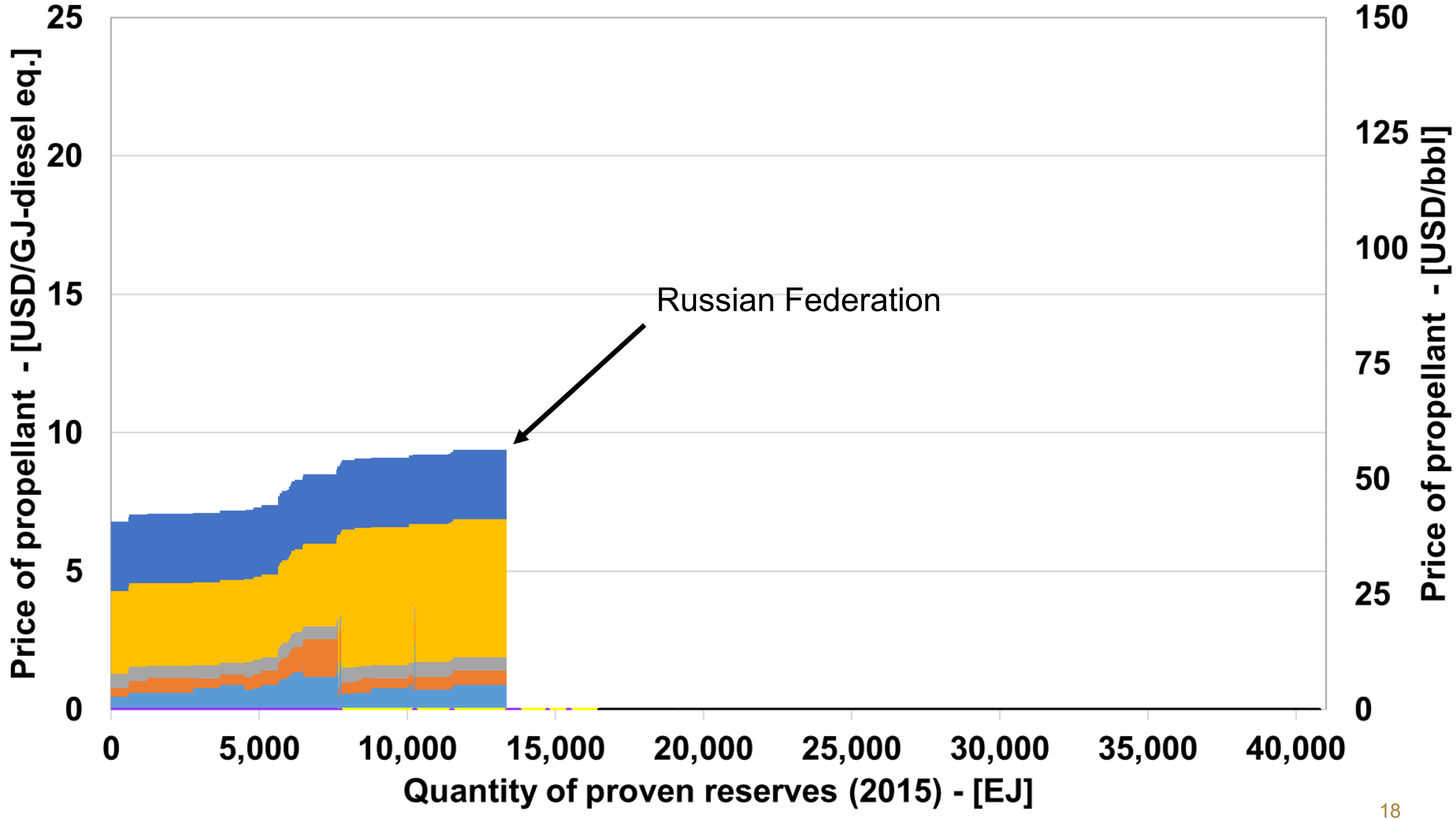

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Algeria
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

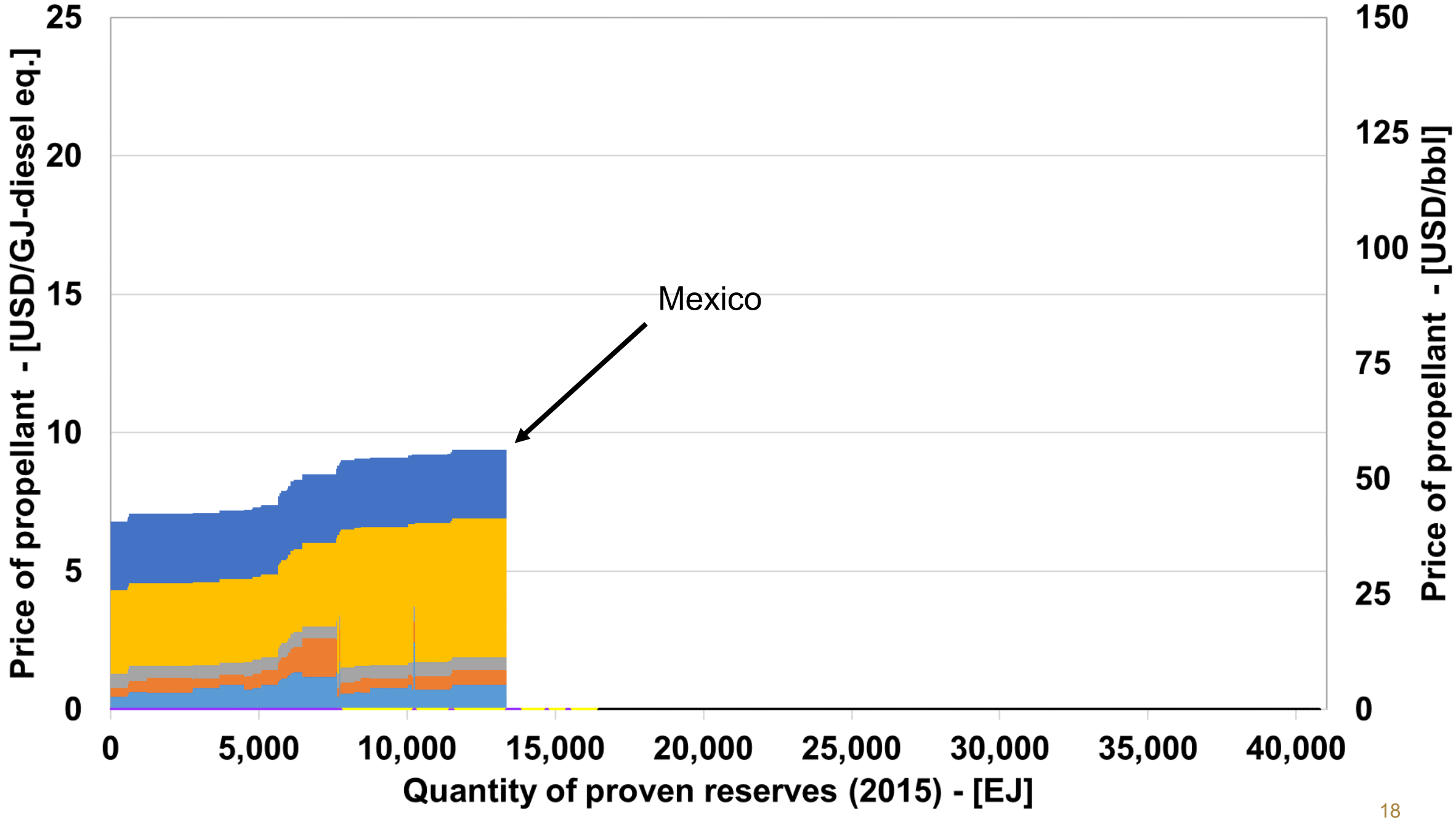

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Mauritania, Tunisia, Afghanistan,
India, and Pakistan
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

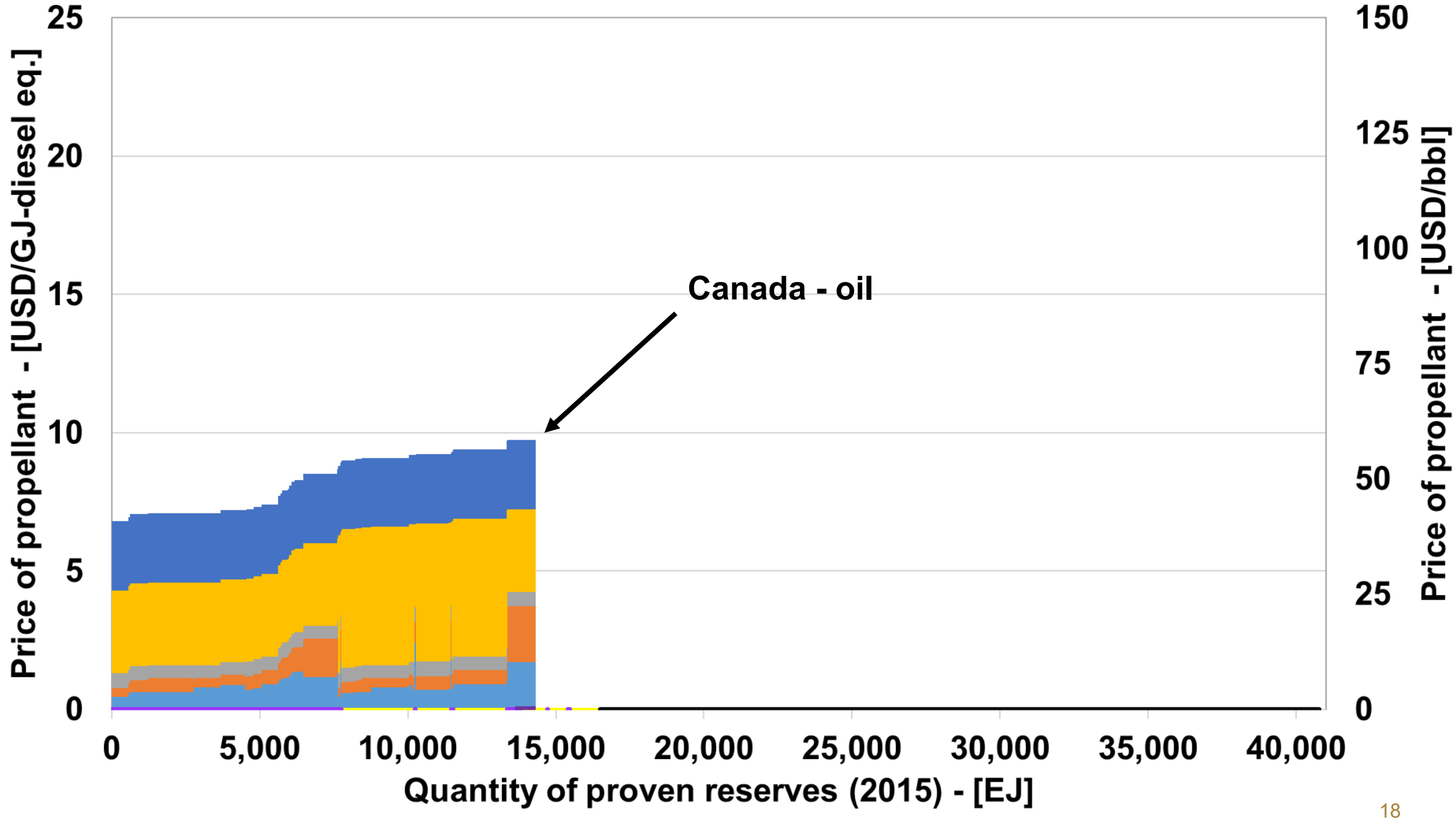

Gabon - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

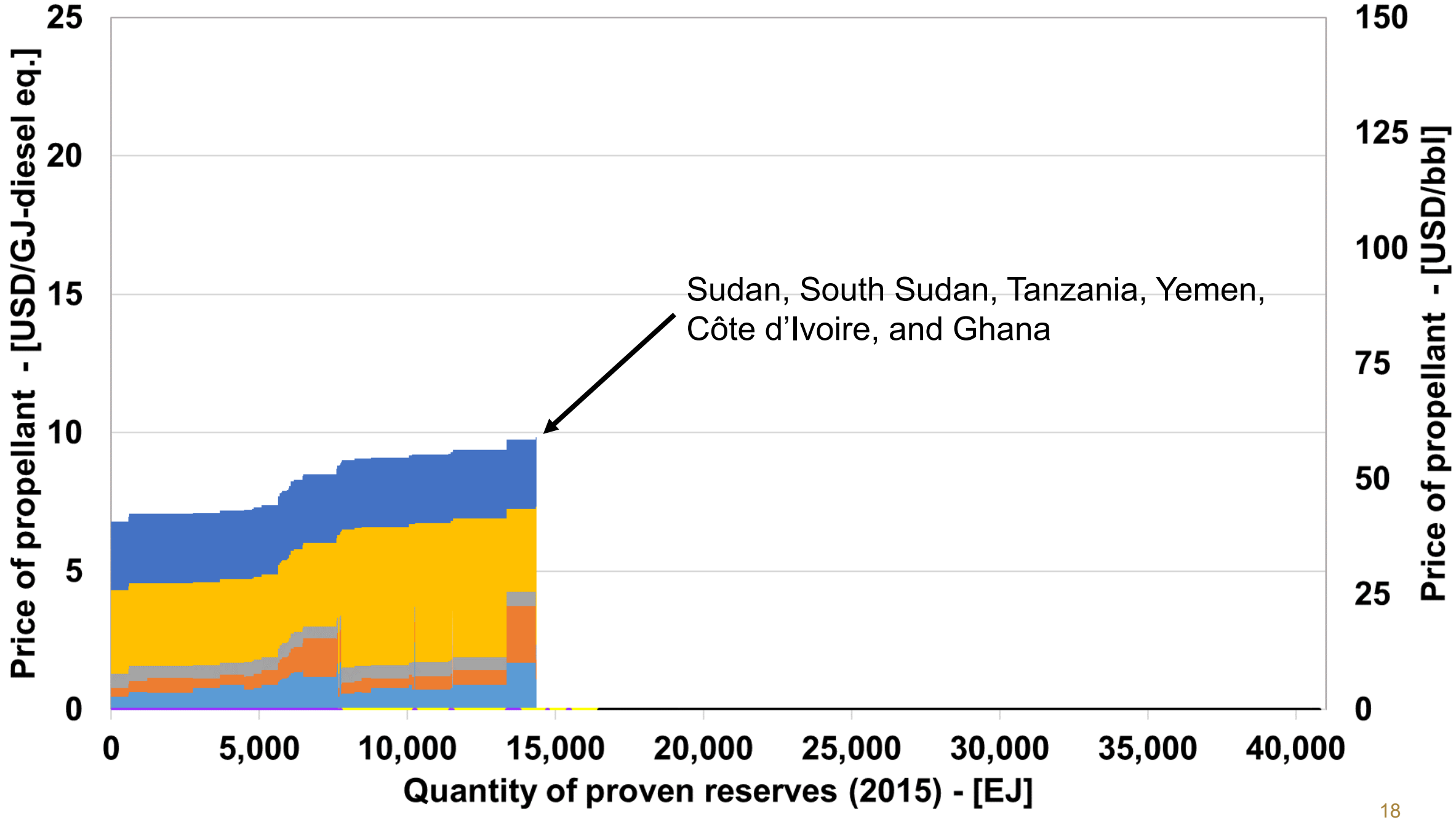

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Libya
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

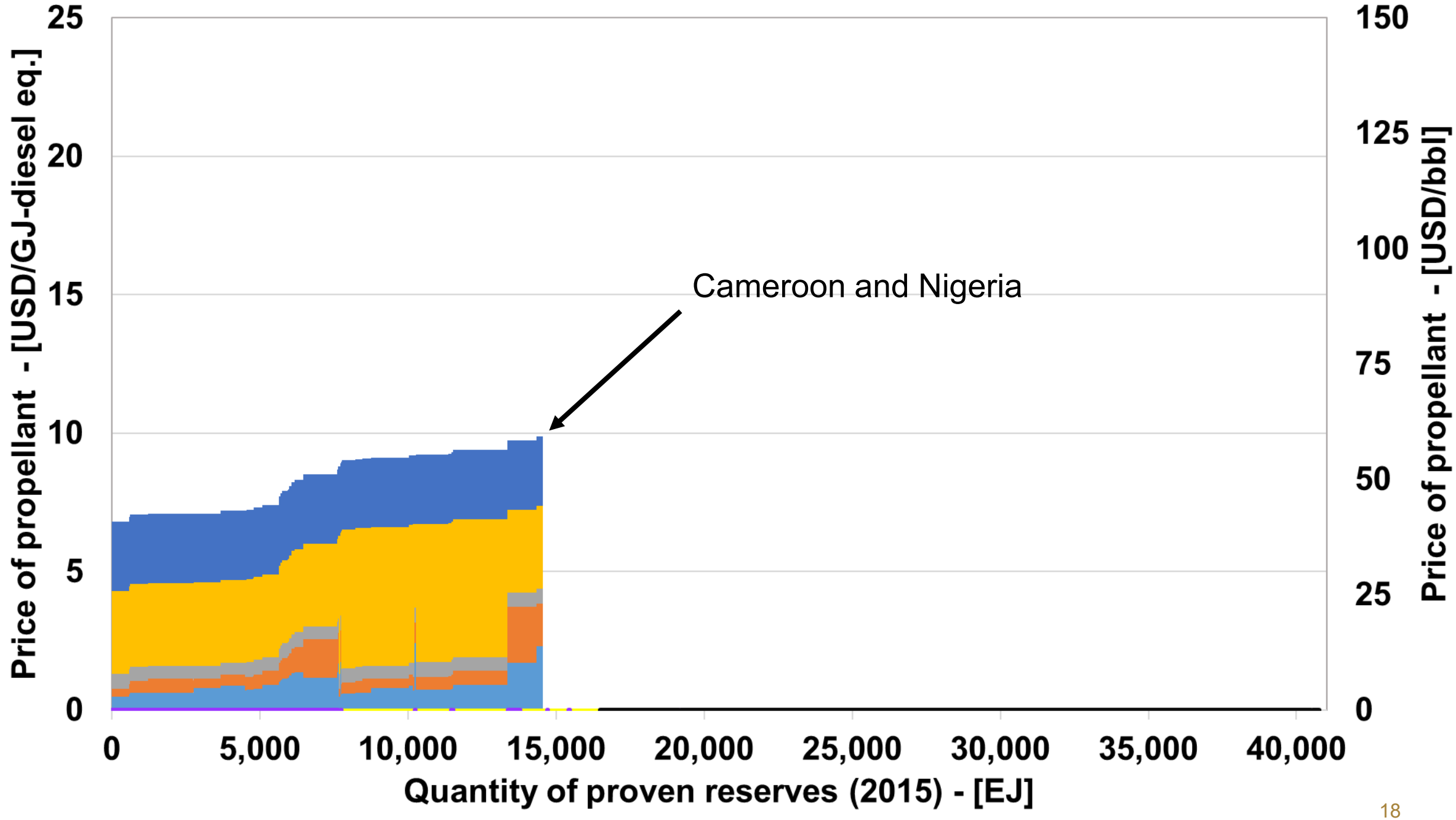

Equatorial Guinea - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

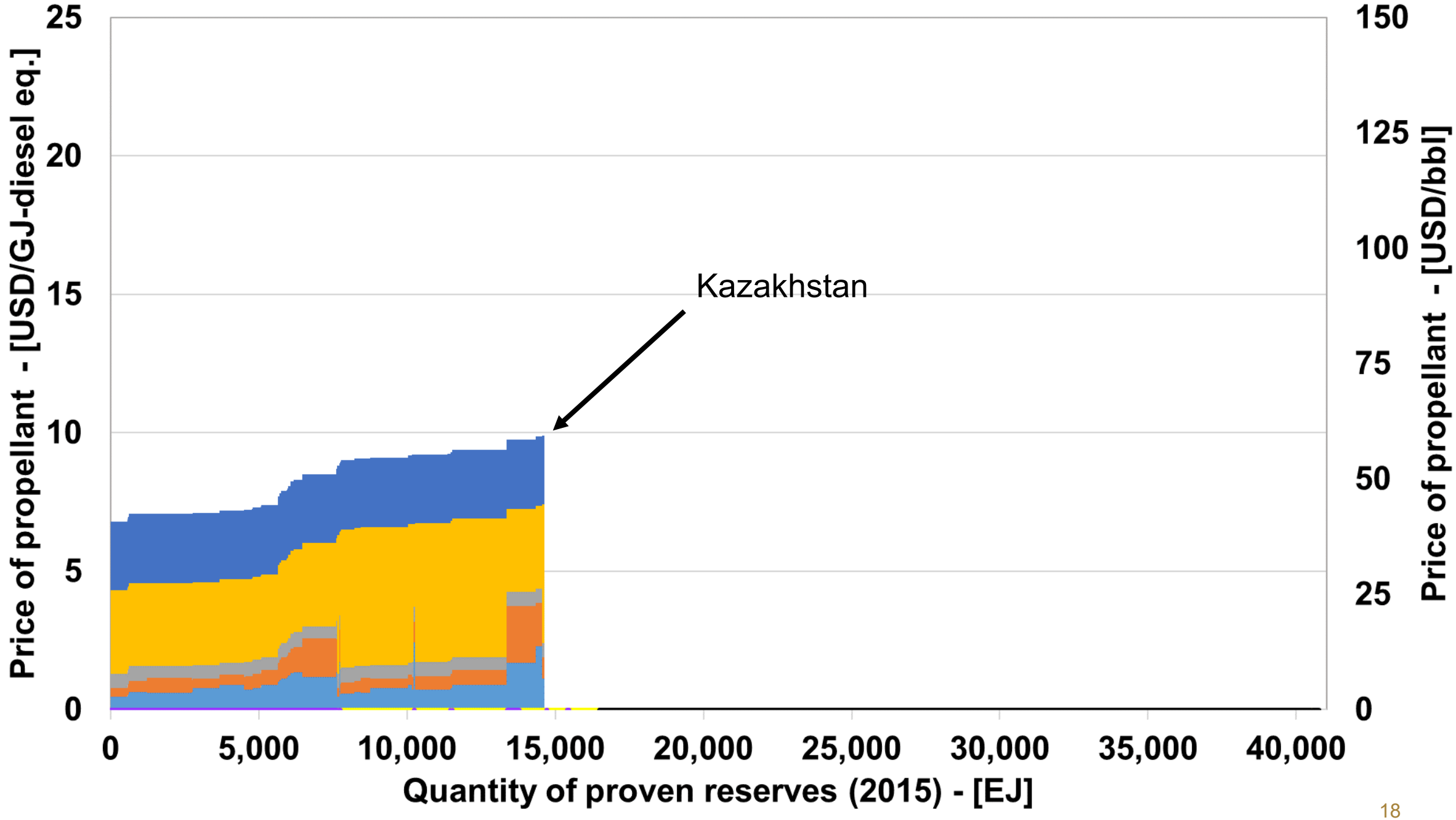

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Russian Federation
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

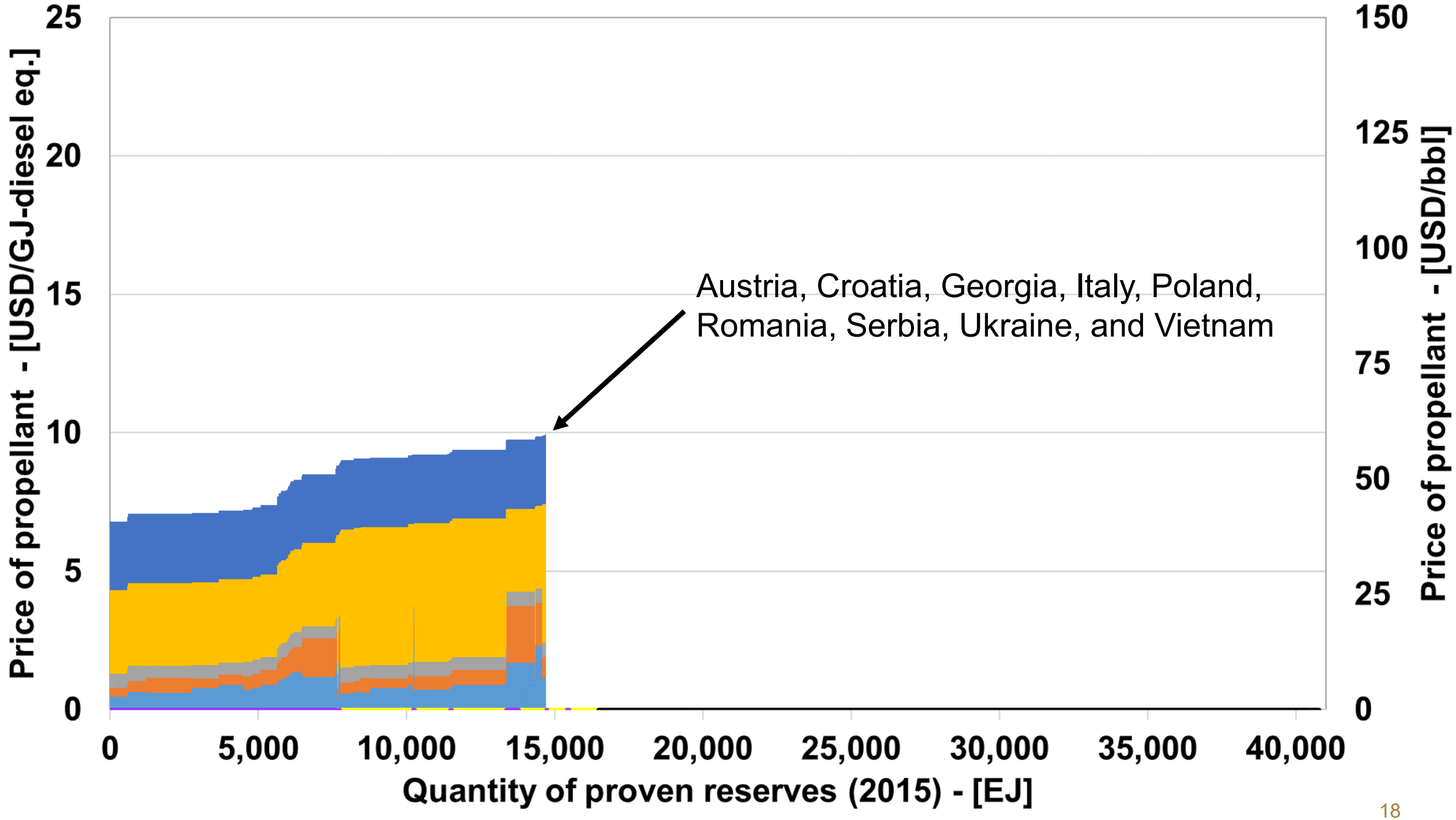

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Mexico
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

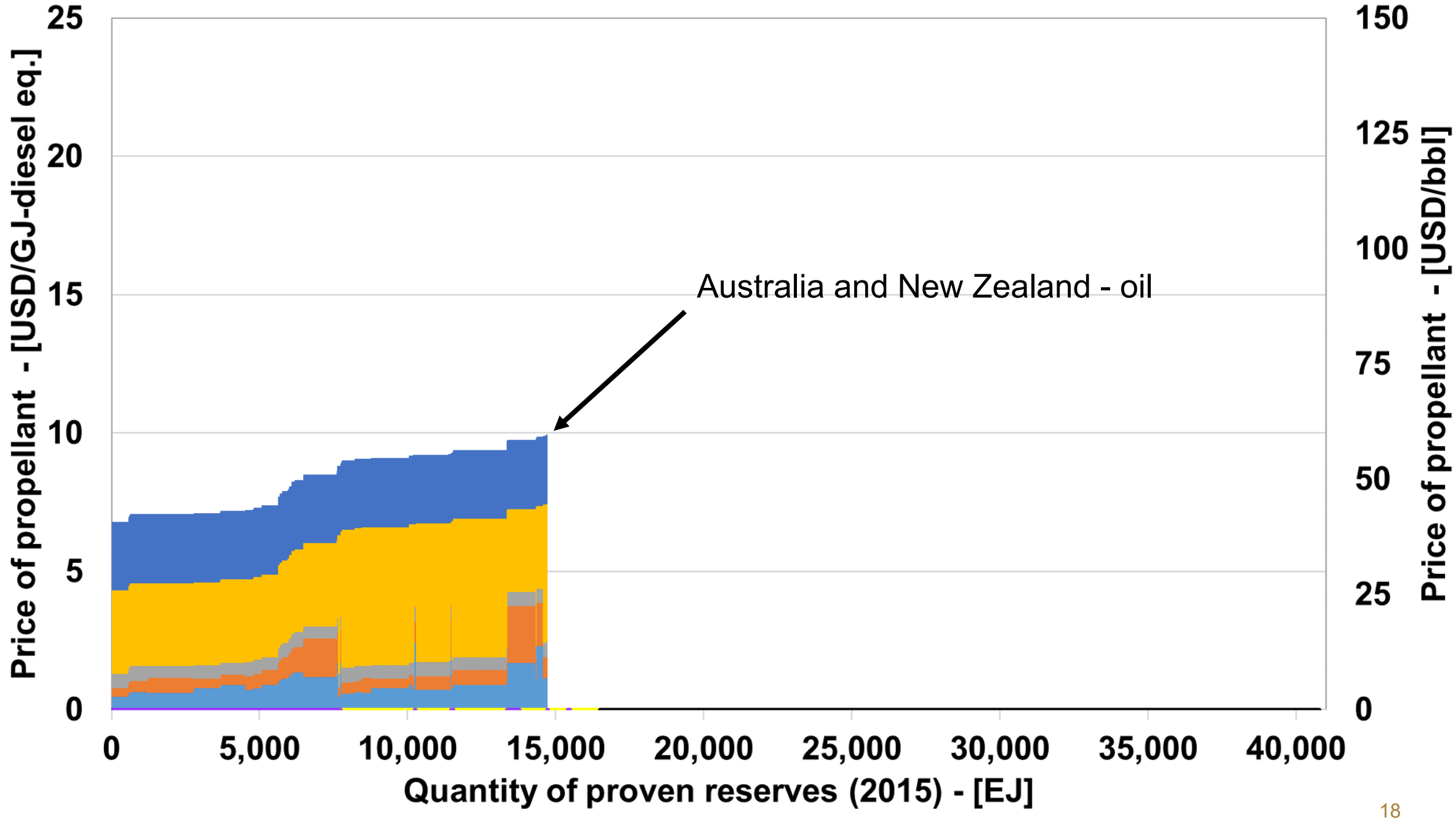

Canada - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

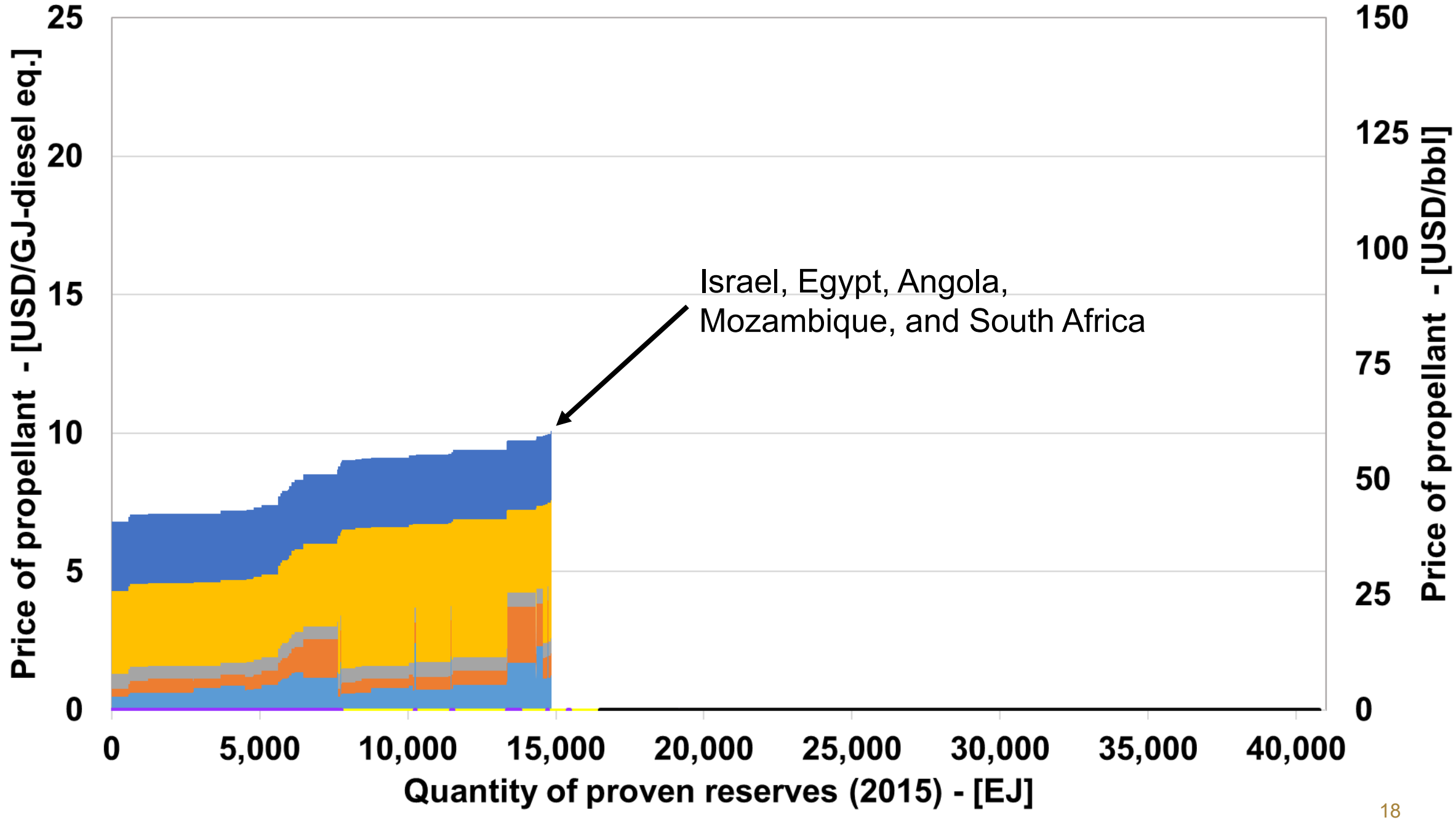

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]
Sudan, South Sudan, Tanzania, Yemen,
Côte d'Ivoire, and Ghana

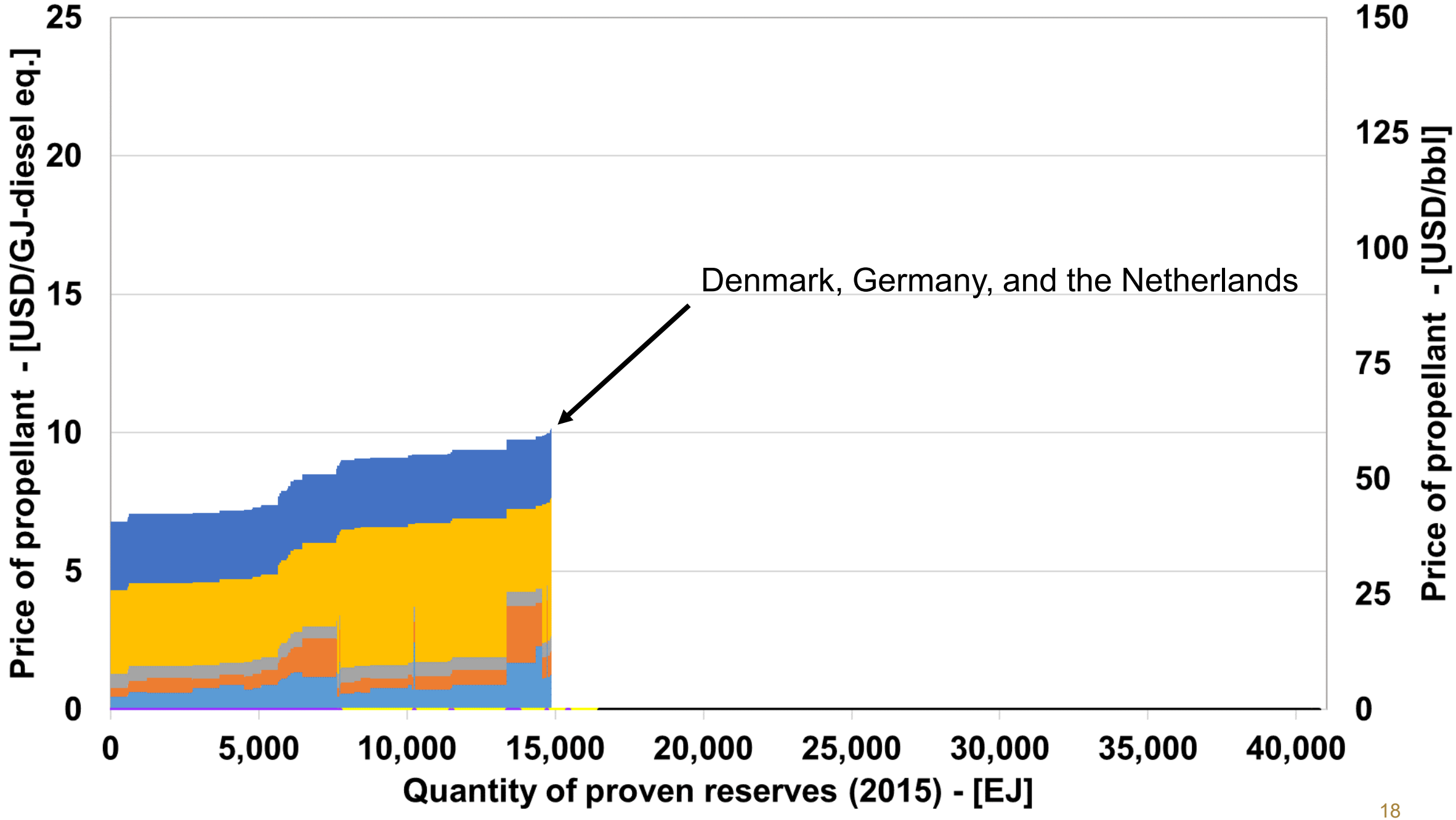

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Cameroon and Nigeria
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

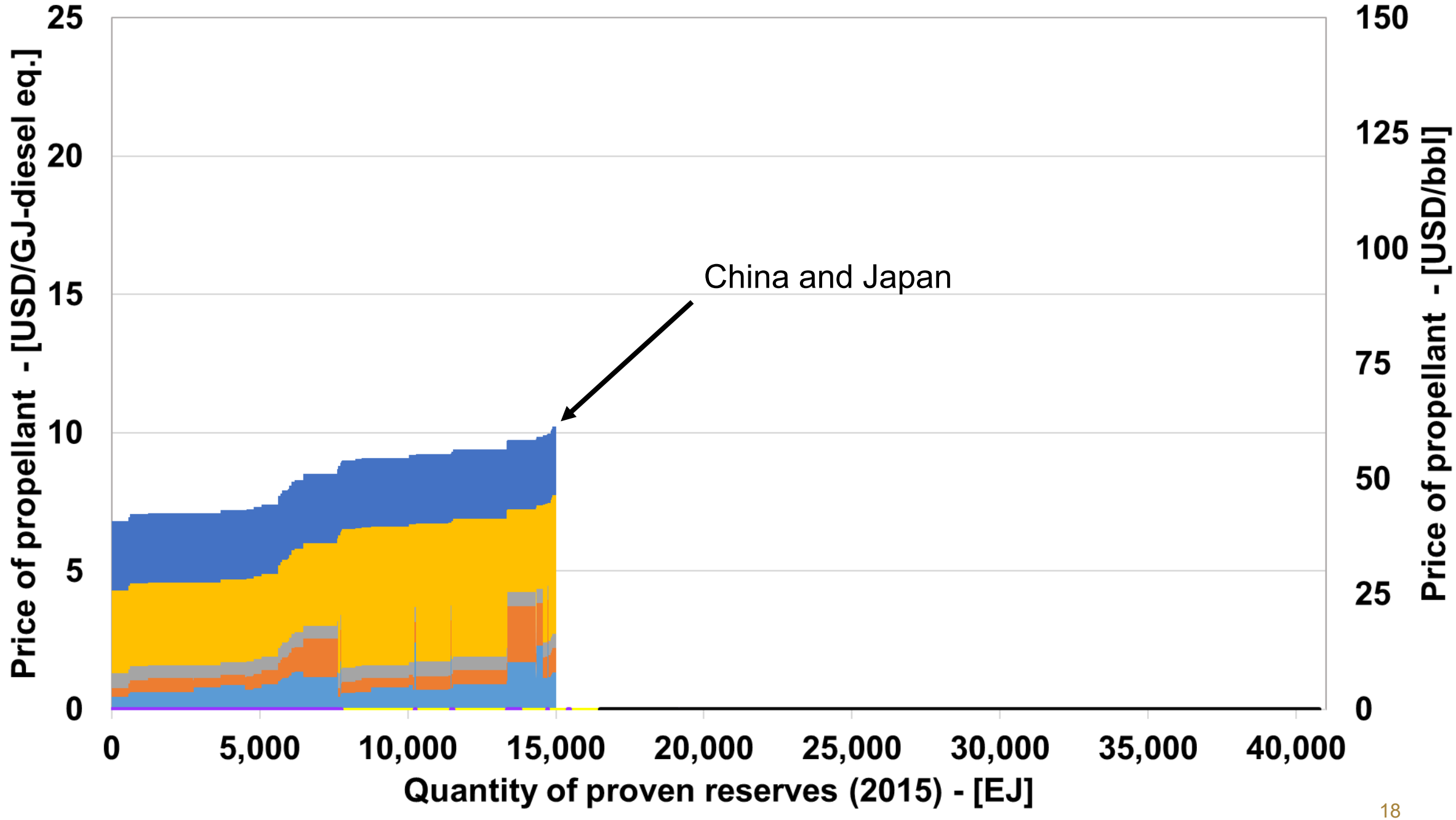

Kazakhstan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

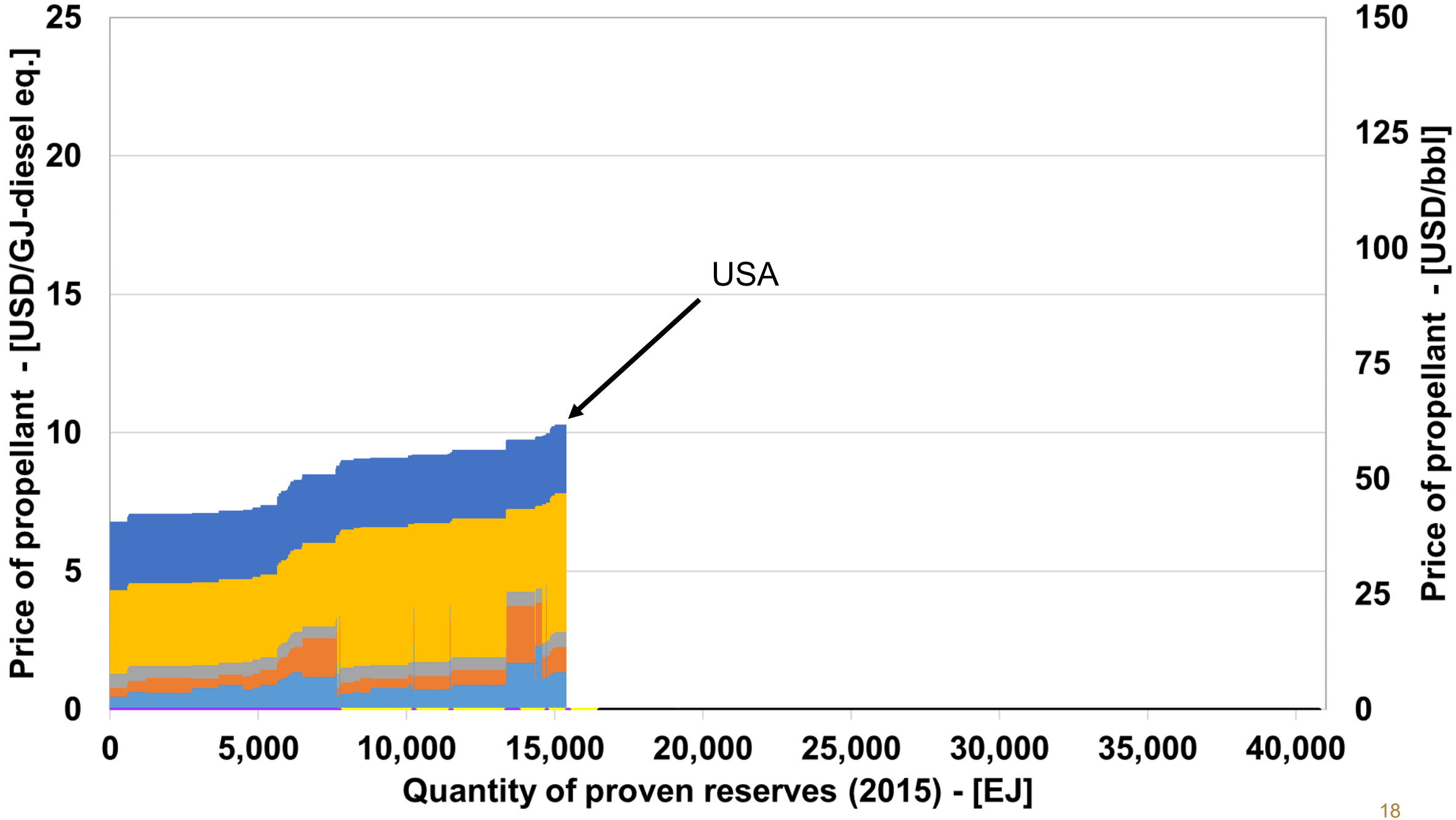

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]
Austria, Croatia, Georgia, Italy, Poland,
Romania, Serbia, Ukraine, and Vietnam

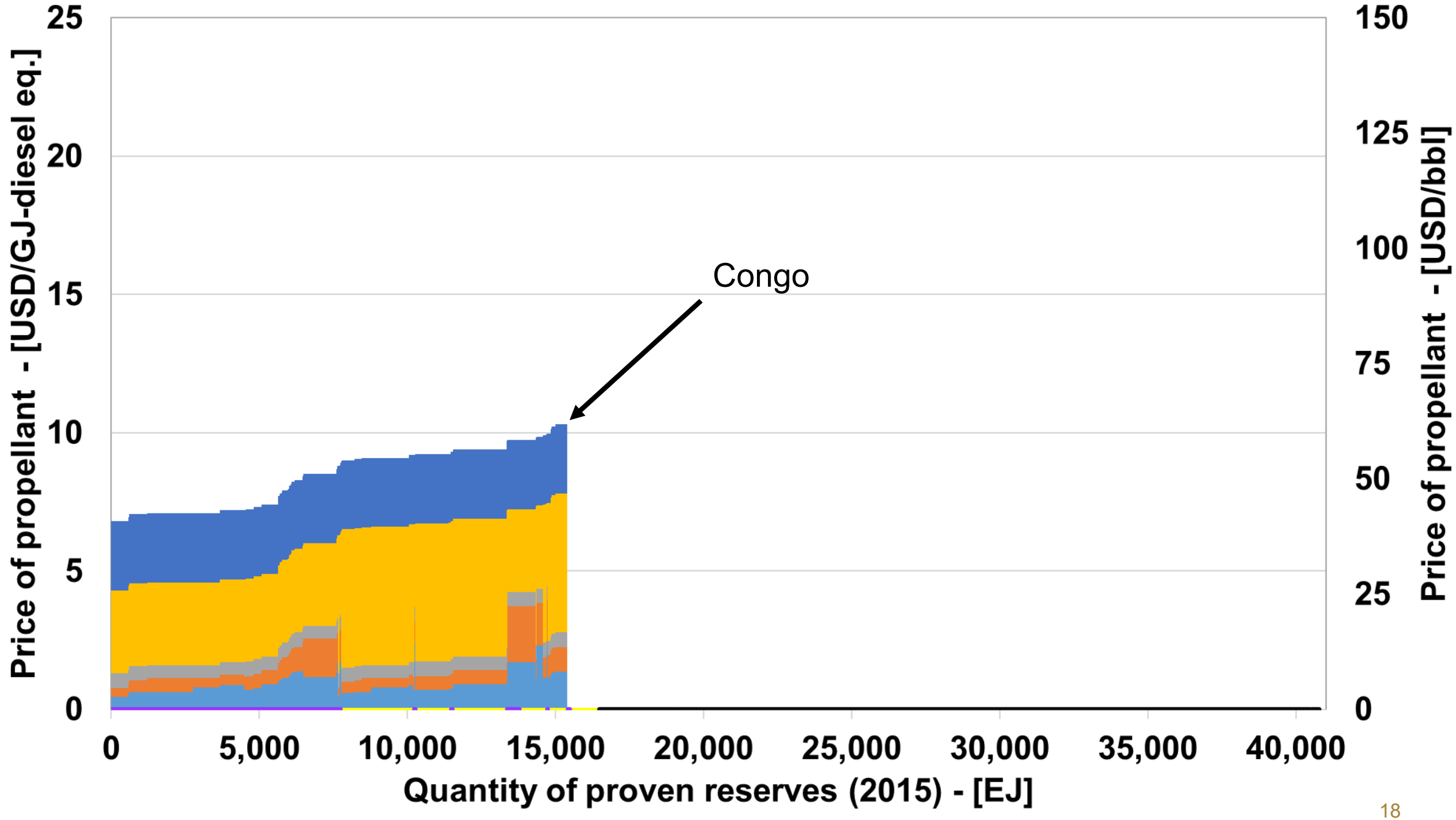

Australia and New Zealand - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

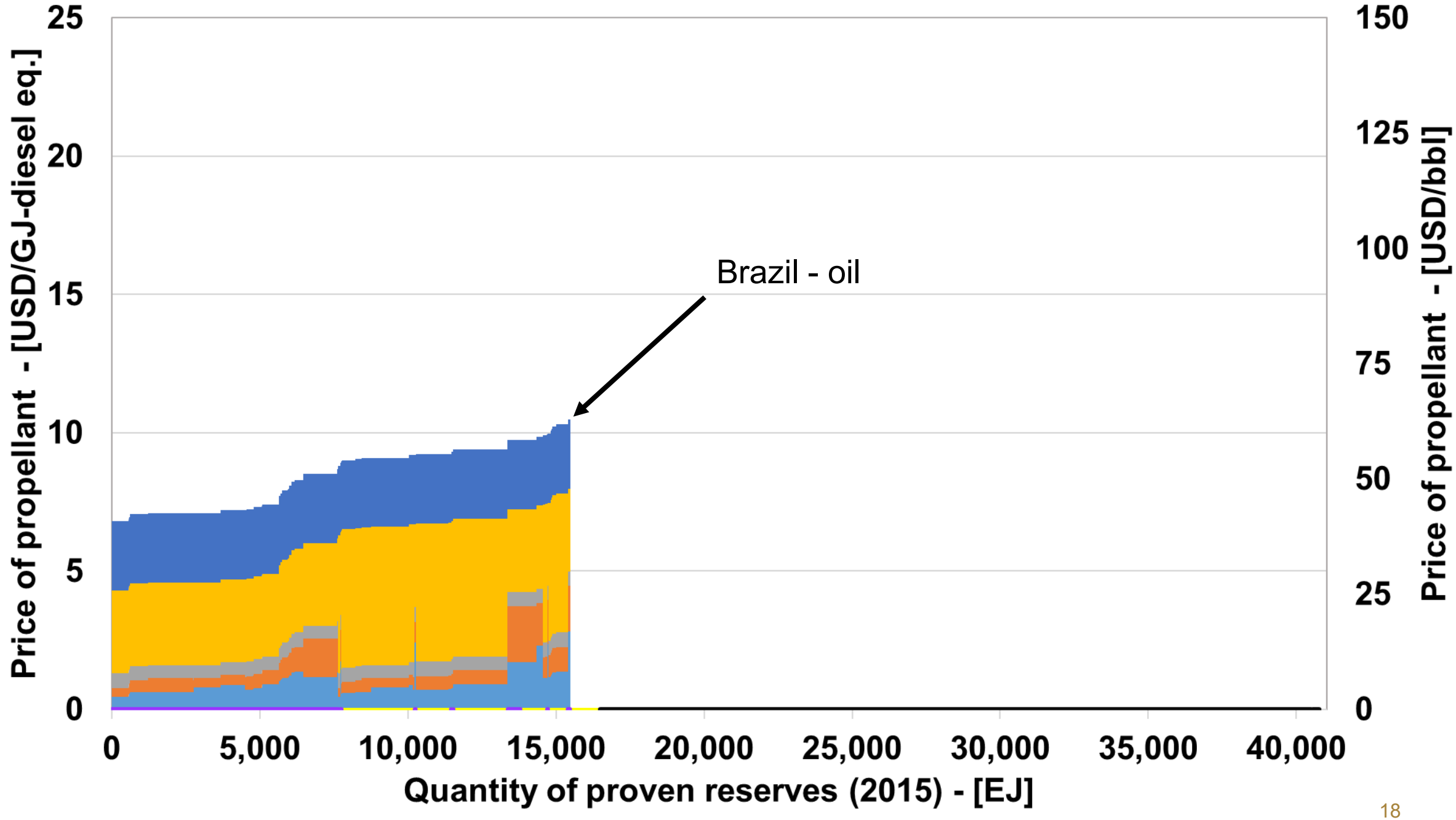

Israel, Egypt, Angola,
Mozambique, and South Africa
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

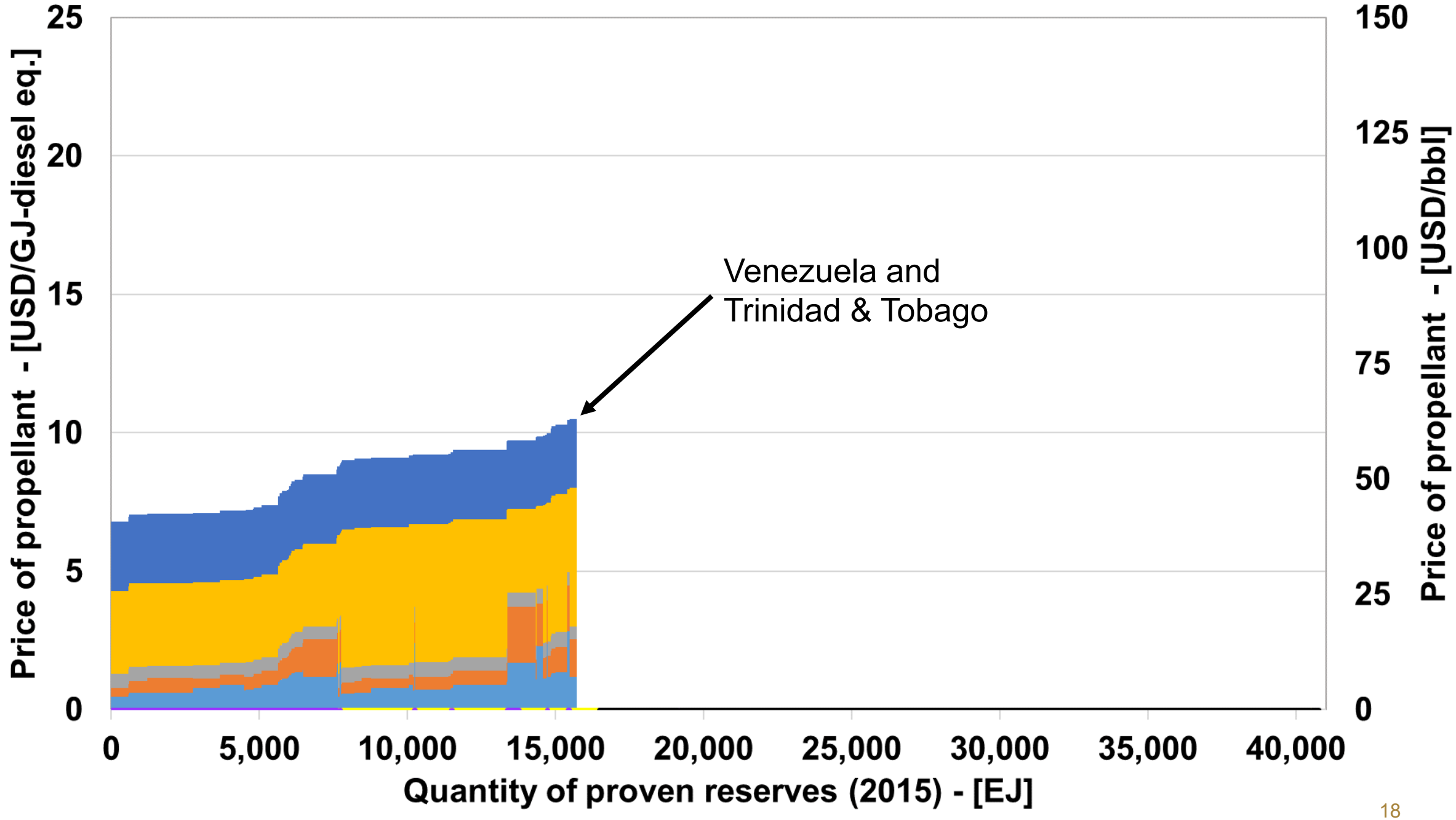

Denmark, Germany, and the Netherlands
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

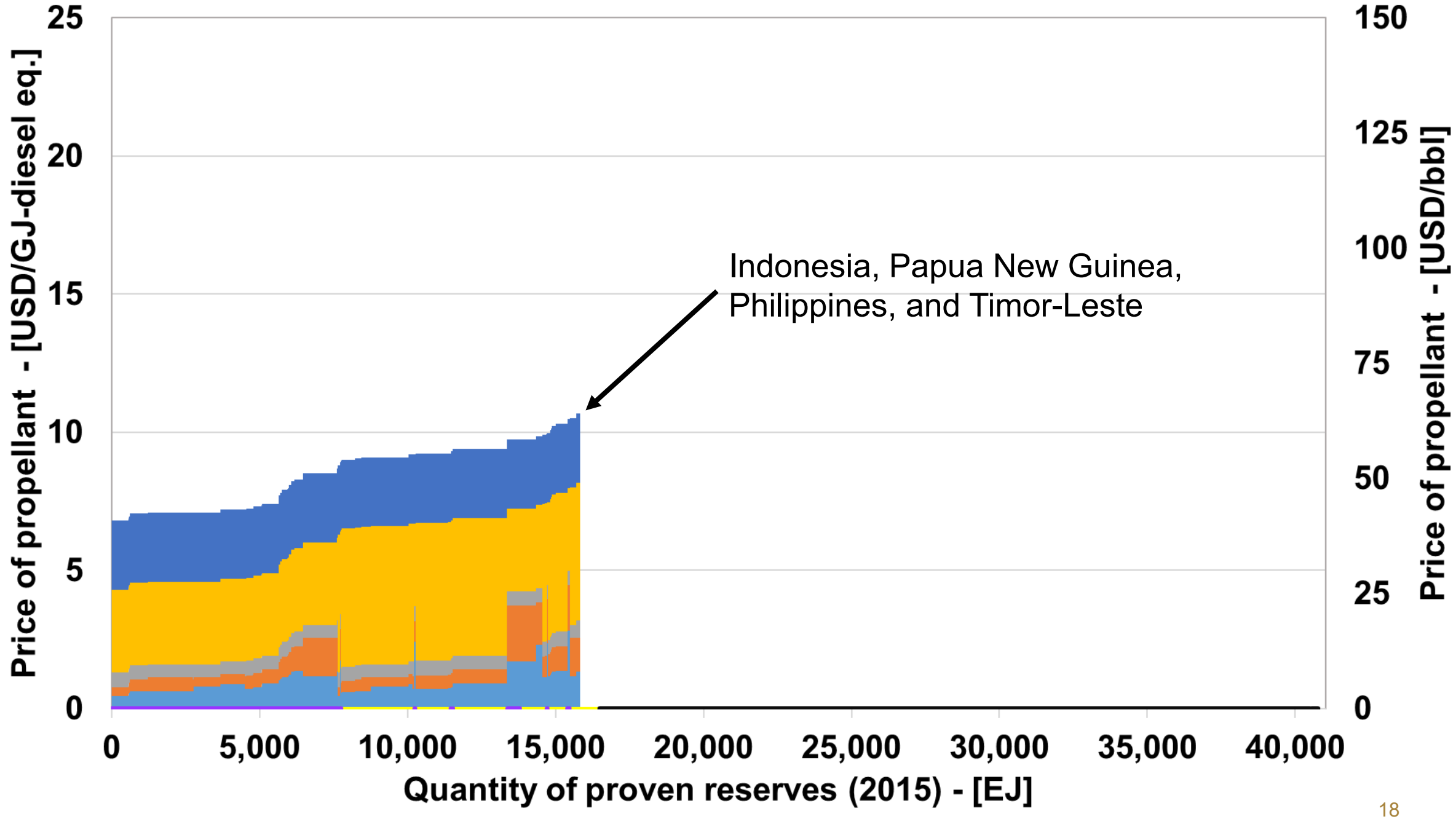

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
China and Japan
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

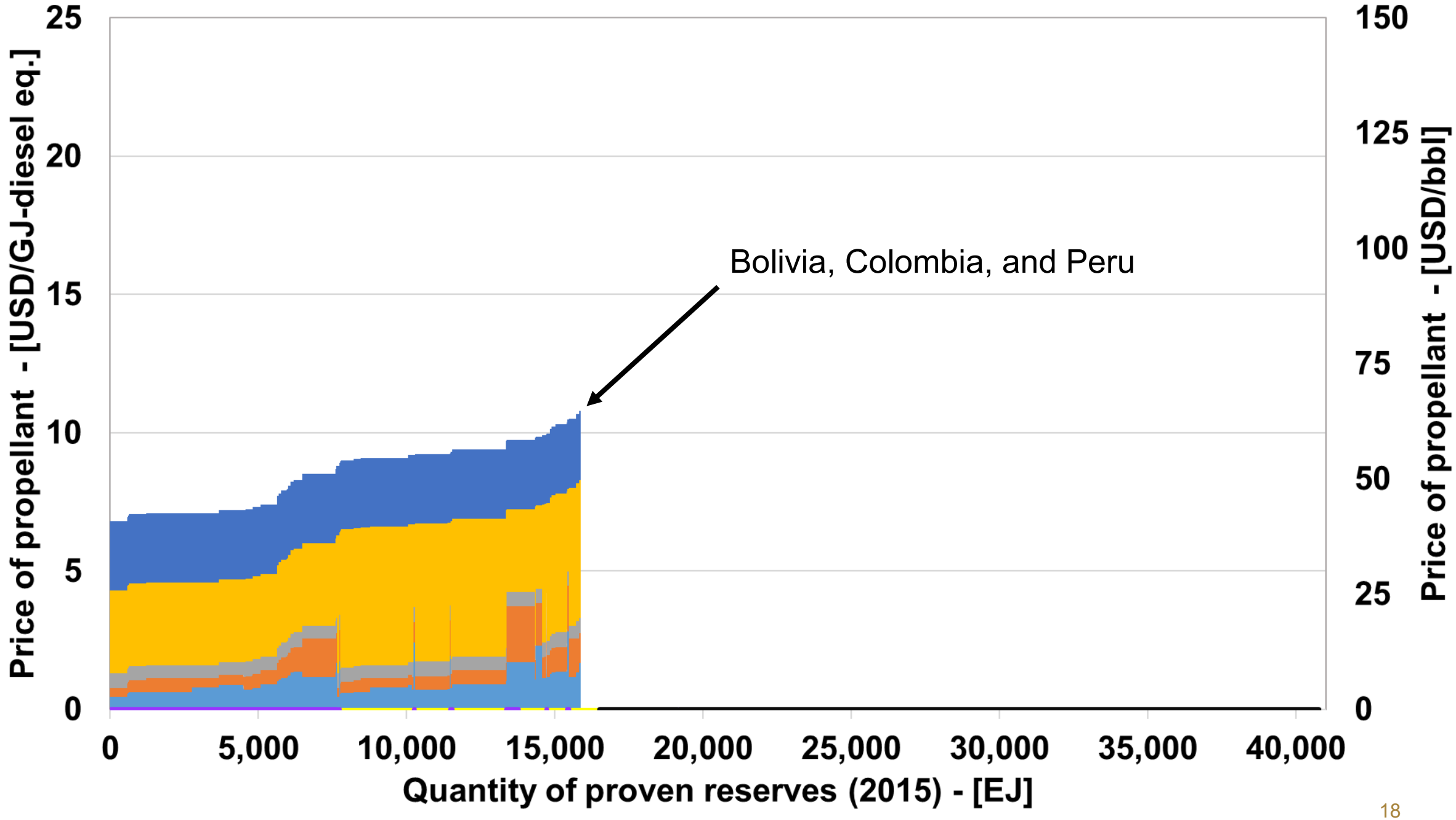

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
USA
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

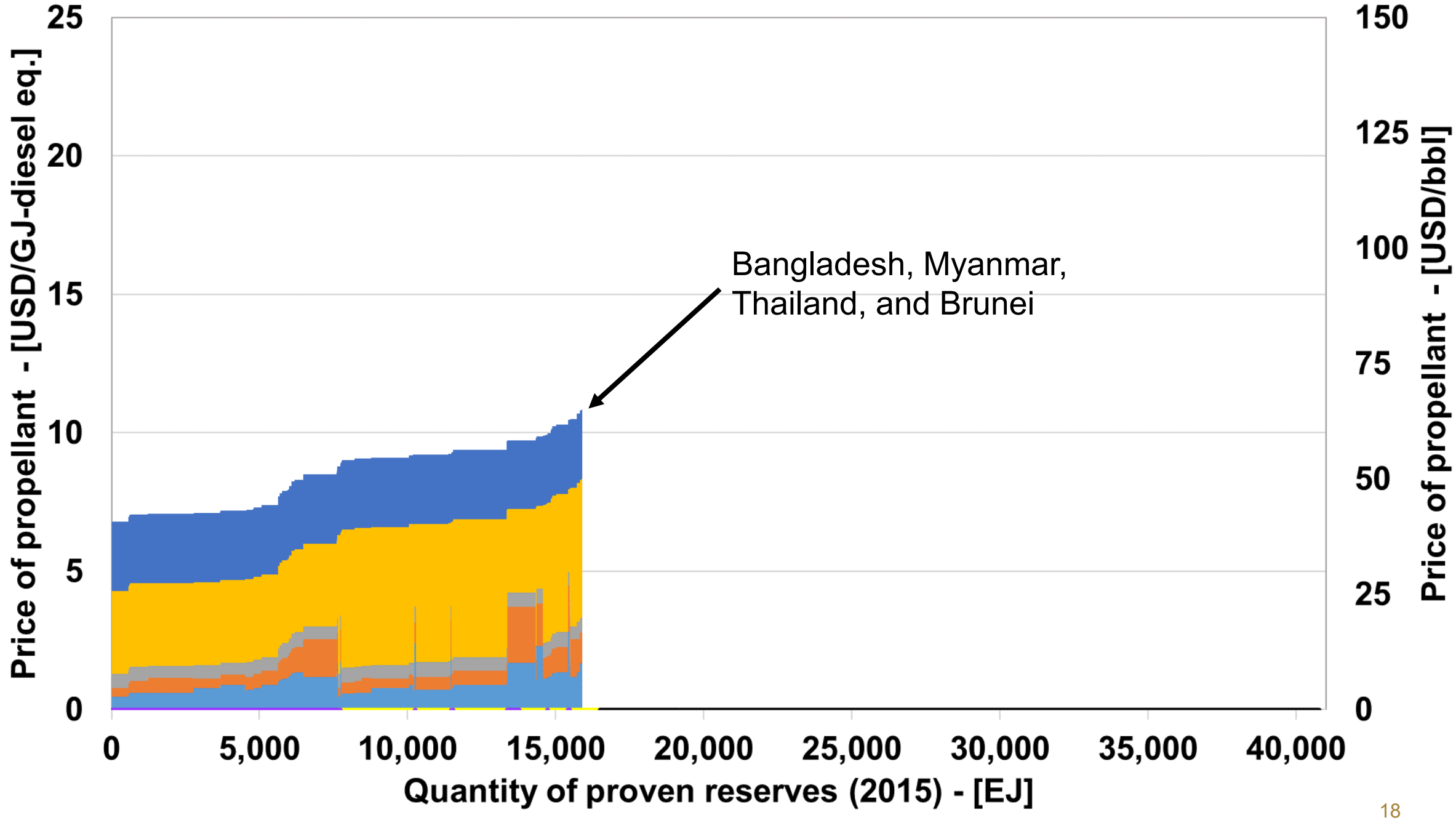

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Congo
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

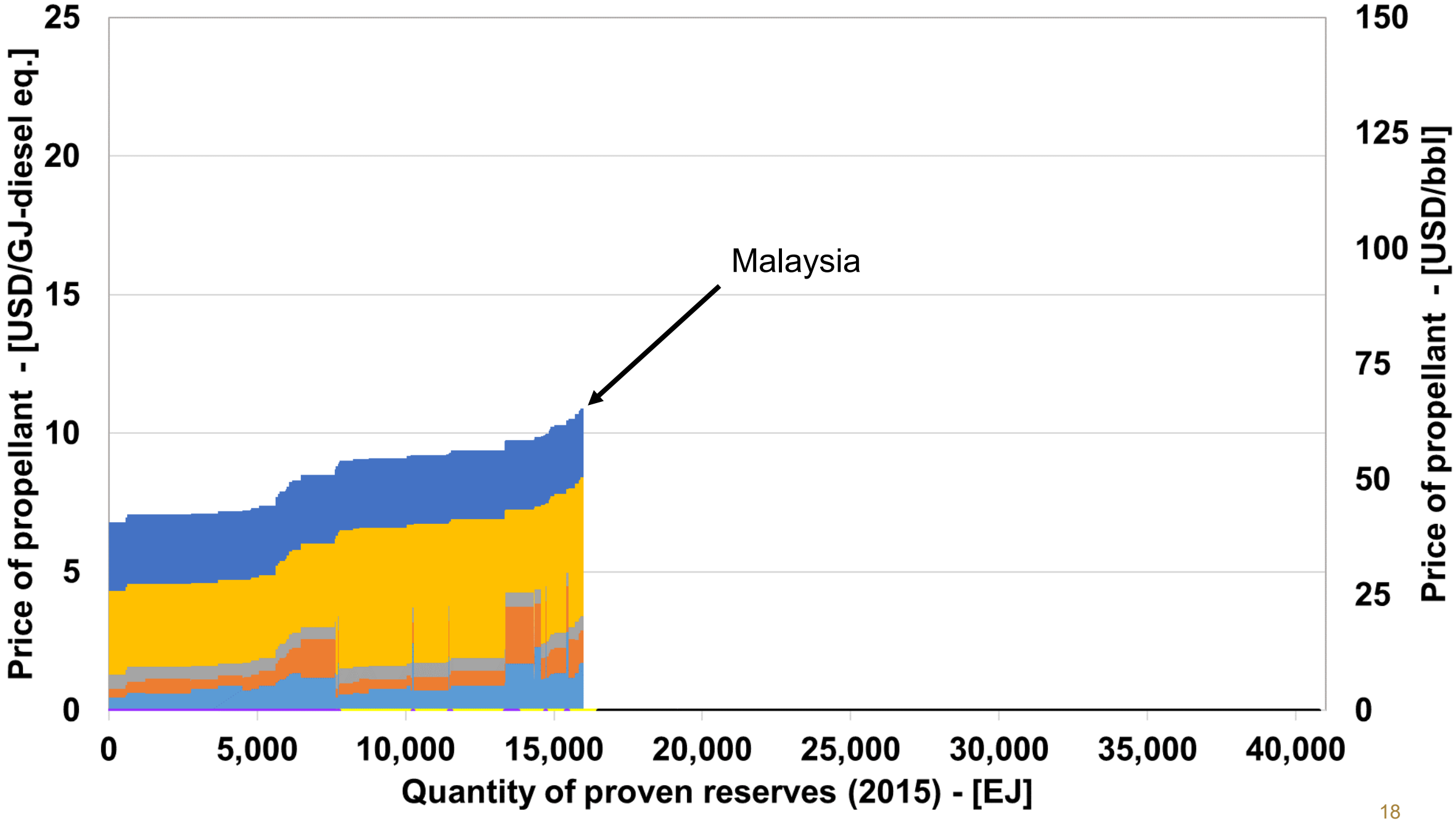

Brazil - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

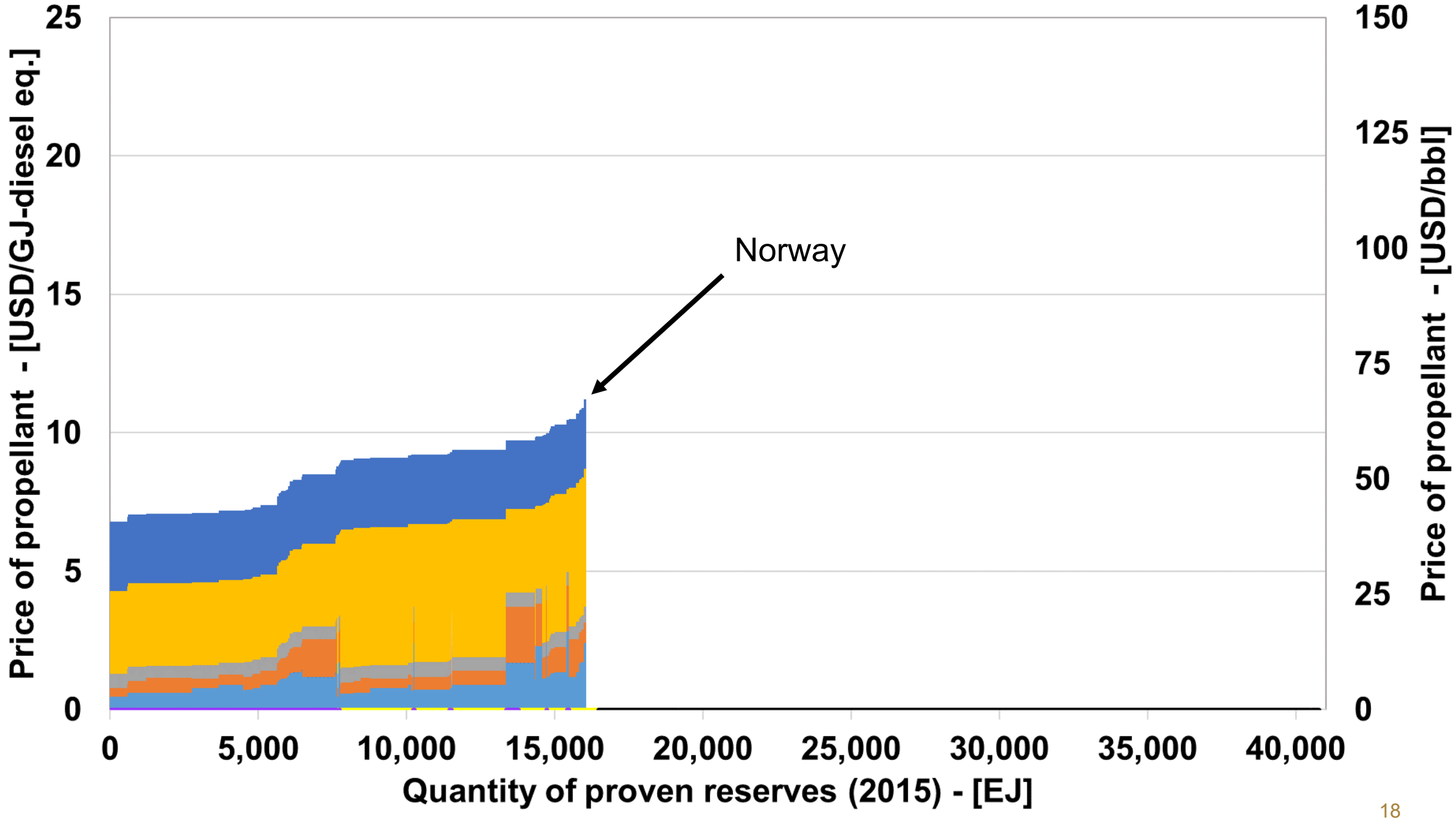

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
150
125
100
75
50
25
0
Price of propellant - [USD/bbl]
Venezuela and
Trinidad & Tobago
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

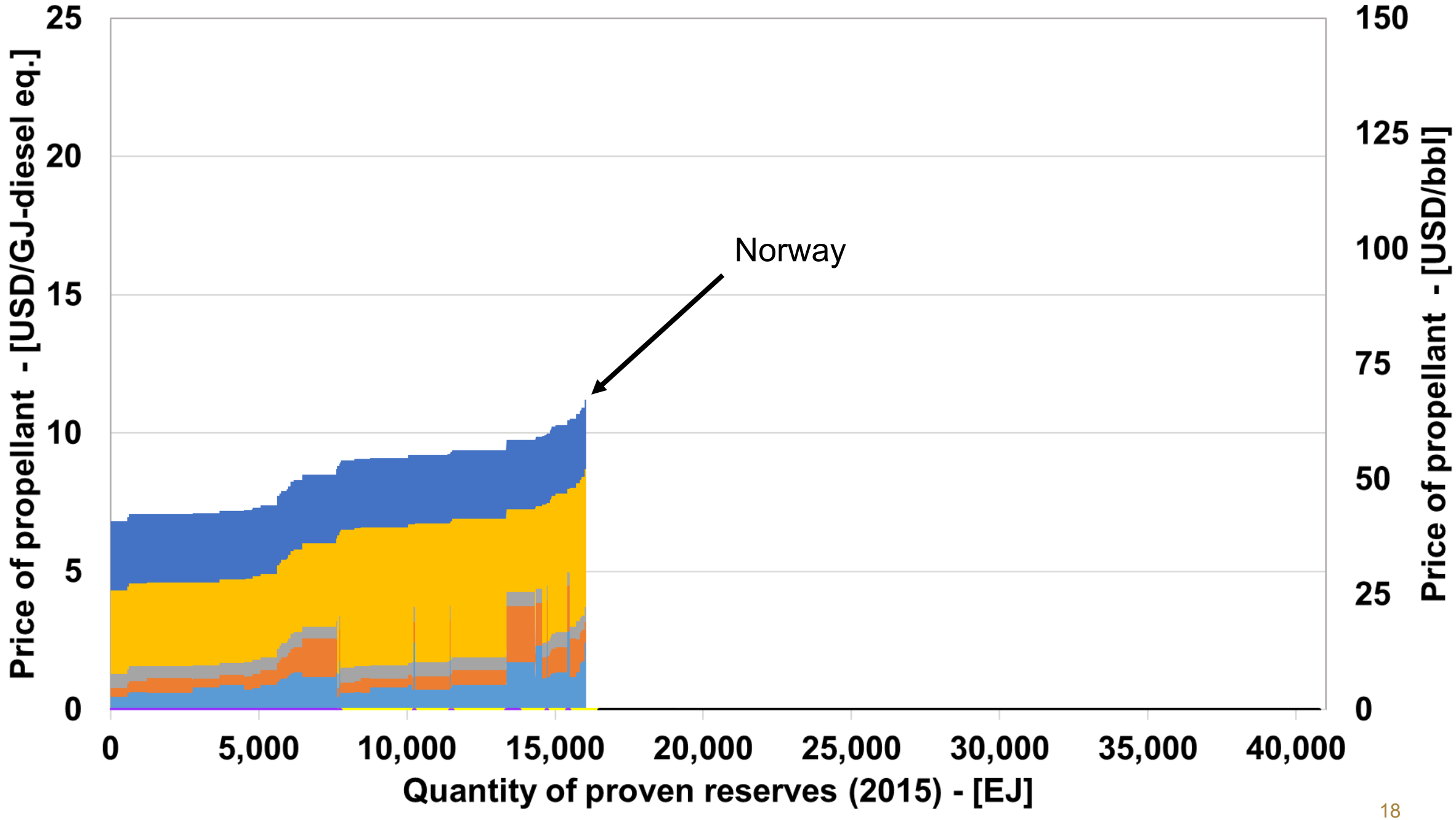

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
Indonesia, Papua New Guinea, Philippines, and Timor-Leste
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

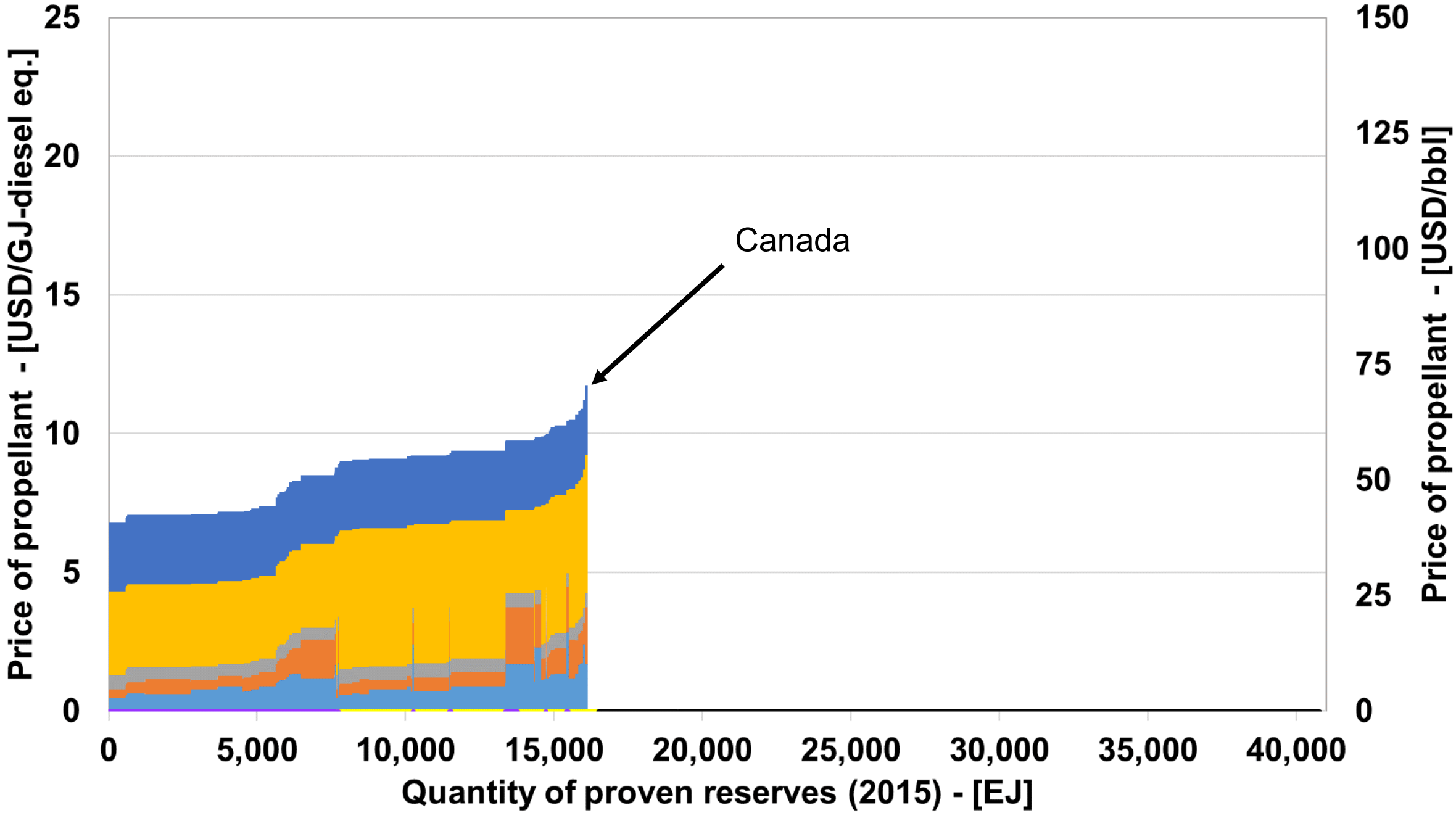

Bolivia, Colombia, and Peru
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

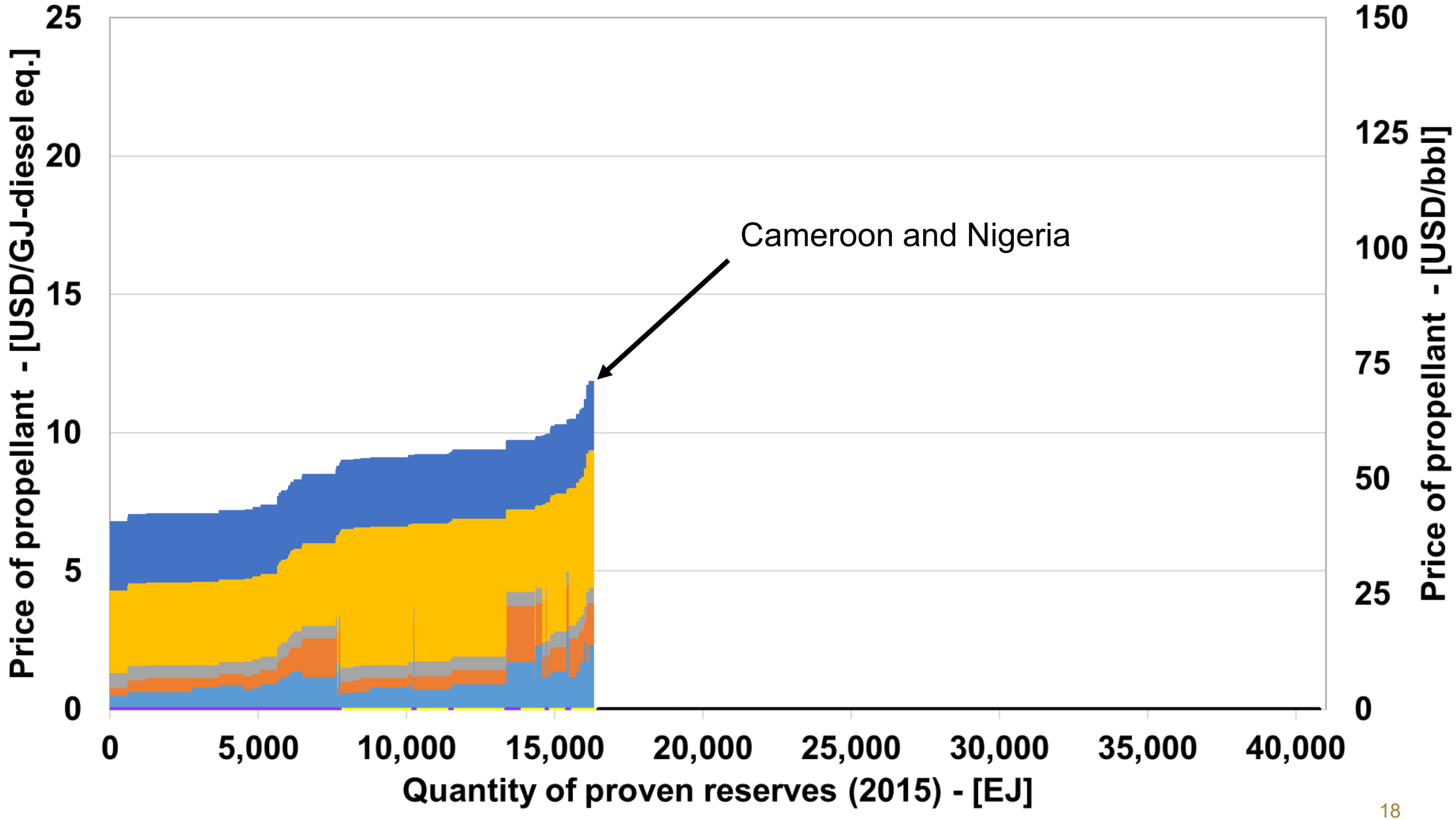

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
150
125
100
75
50
25
0
Price of propellant - [USD/bbl]
Bangladesh, Myanmar,
Thailand, and Brunei
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]

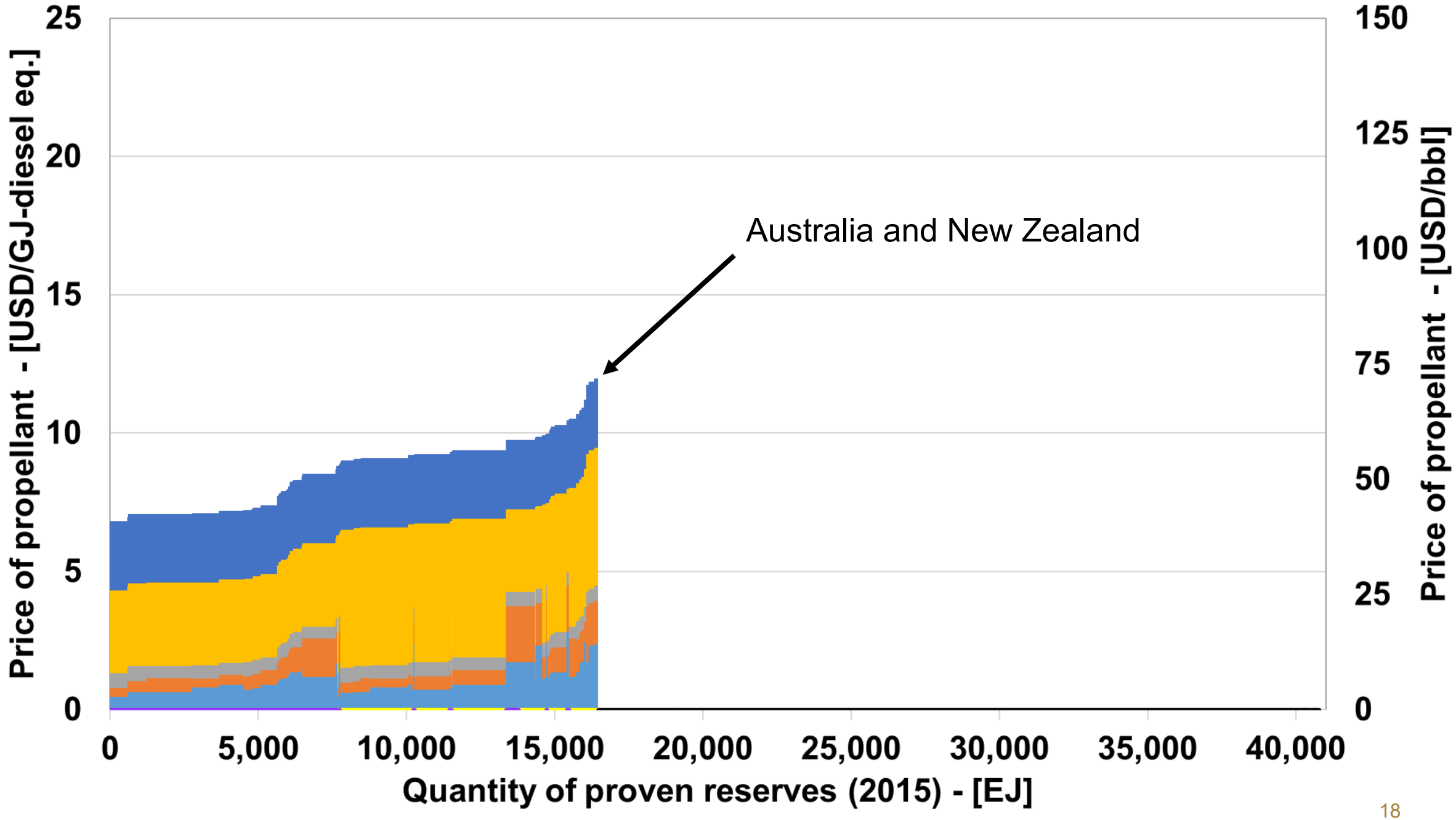

Malaysia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000

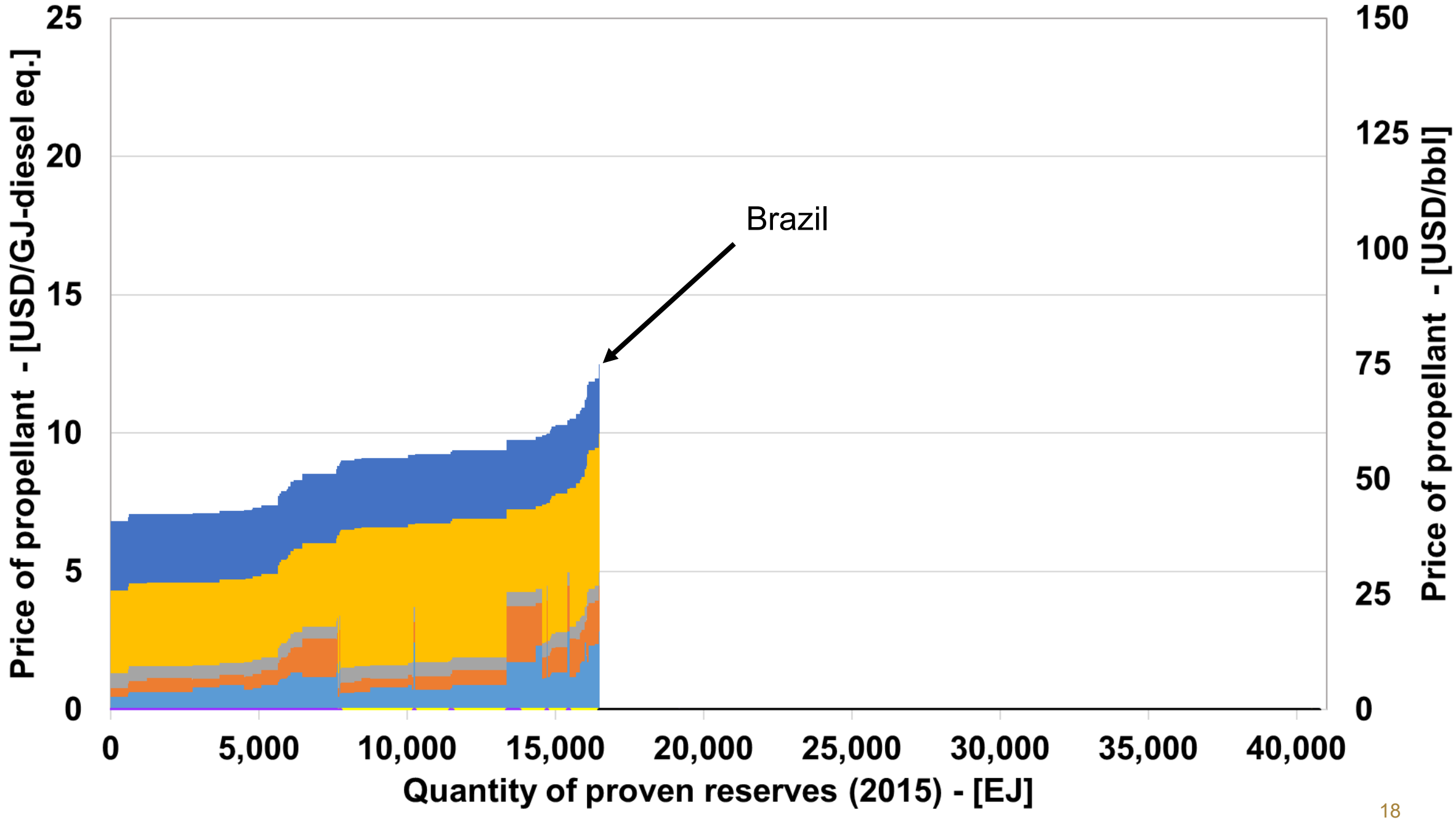

Norway
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000


Norway
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000


Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
150
125
100
75
50
25
0
Price of propellant - [USD/bbl]
Canada
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]


Cameroon and Nigeria
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000


Australia and New Zealand
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000


Brazil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
0
5,000
10,000
15,000
20,000
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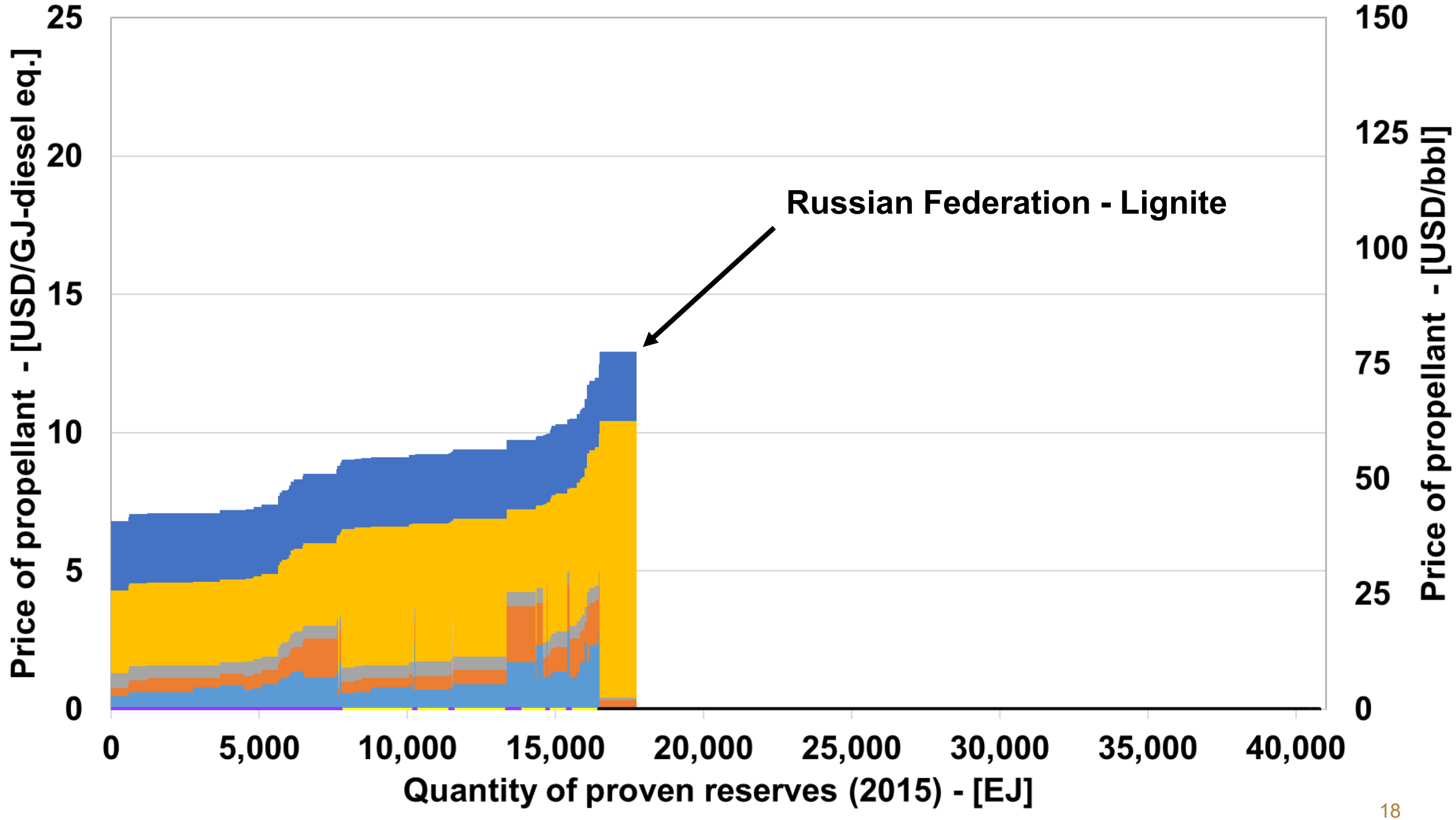
Russian Federation - Lignite
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
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5,000
10,000
15,000
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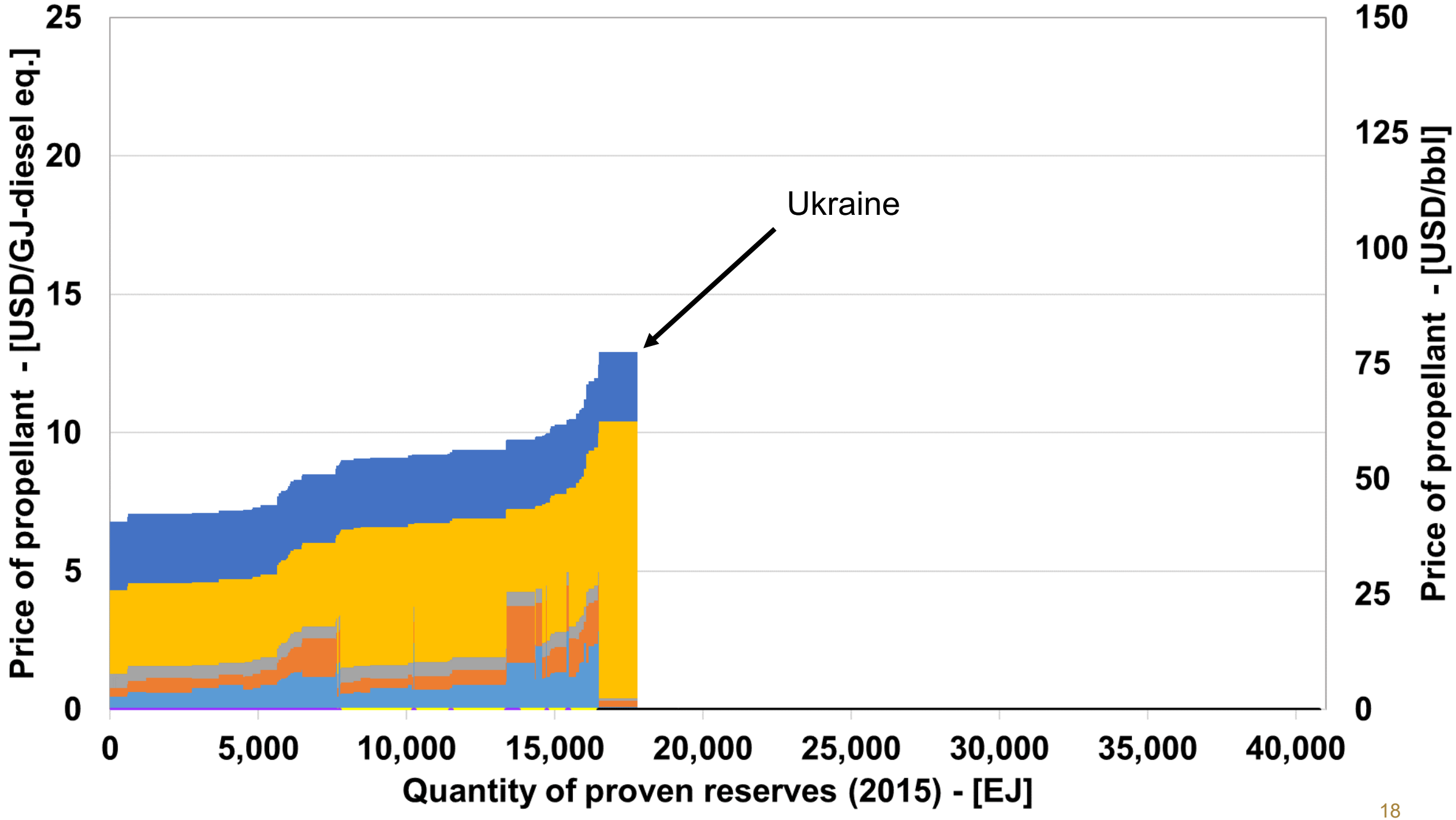
Ukraine
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
50
75
100
125
150
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5,000
10,000
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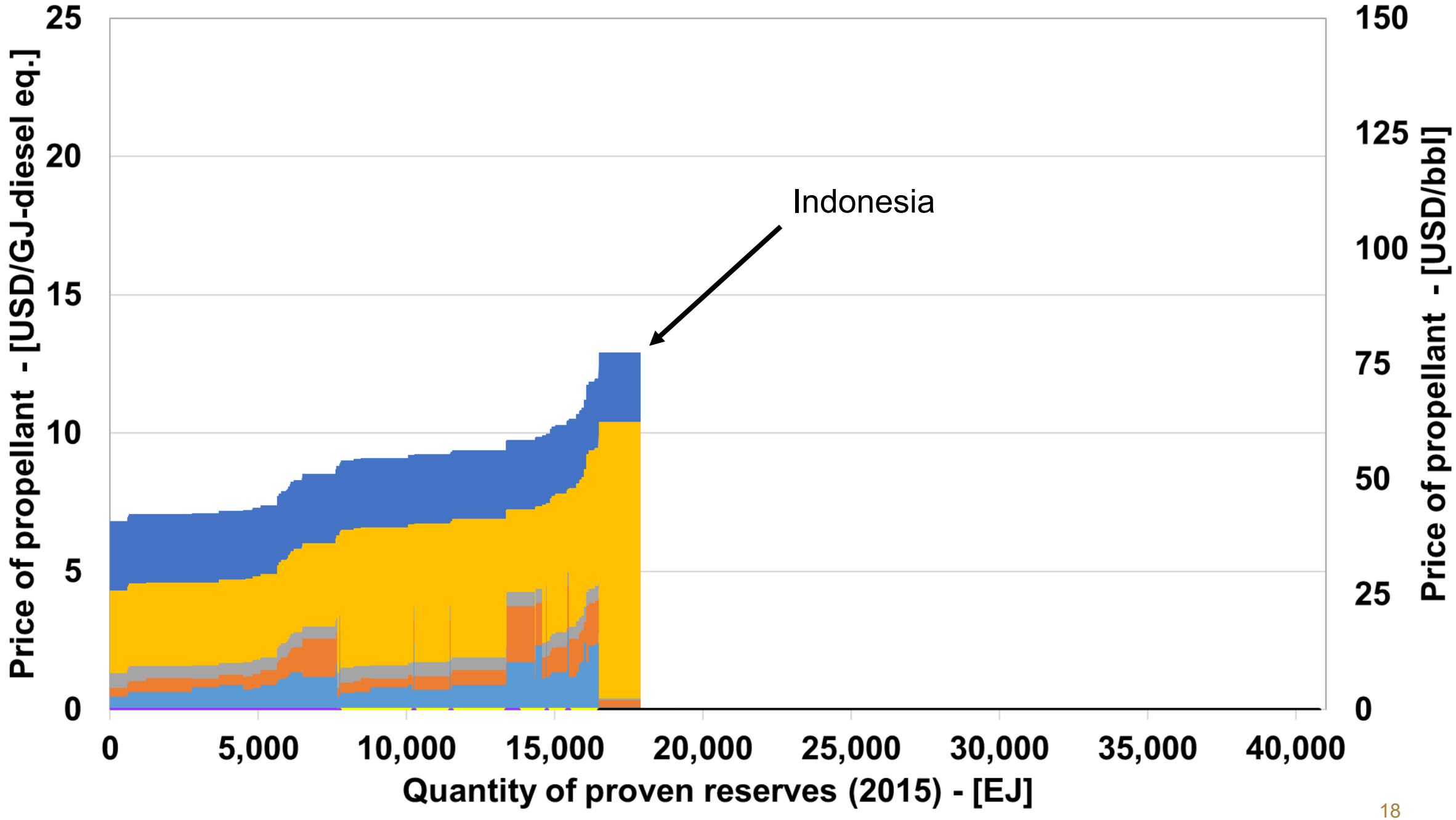
Indonesia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
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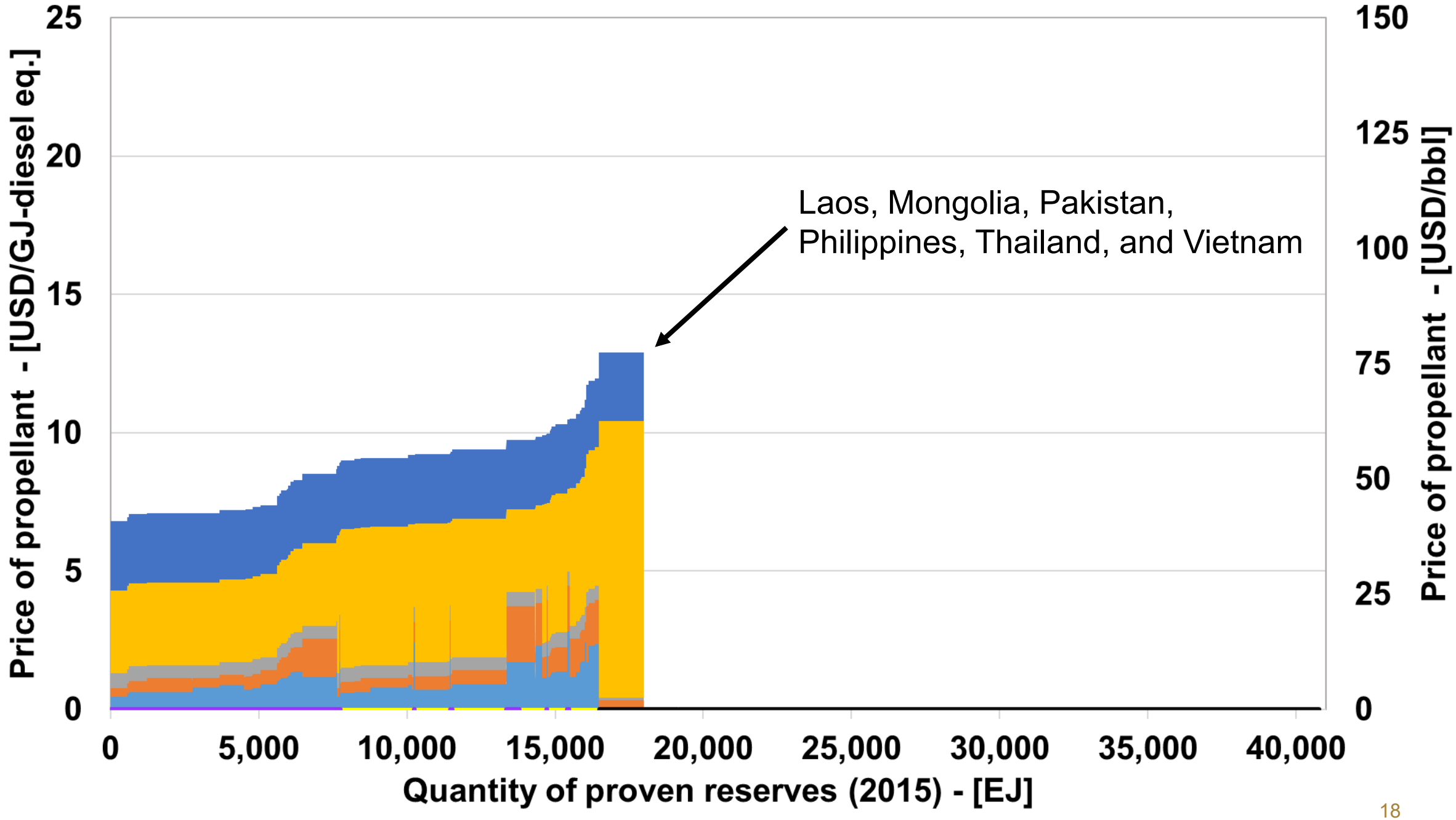
Laos, Mongolia, Pakistan,
Philippines, Thailand, and Vietnam
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
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25
0
25
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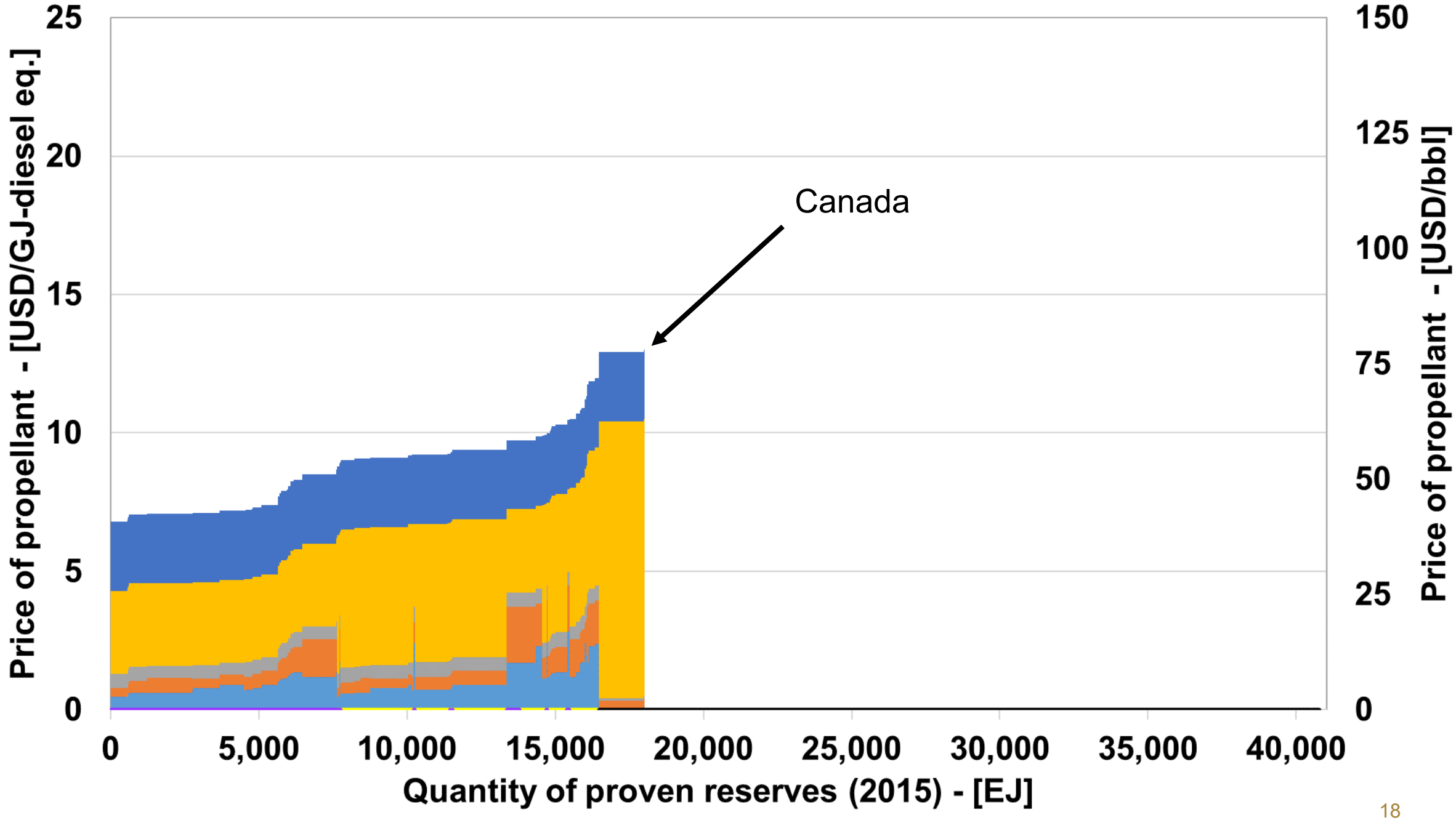
Canada
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
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25
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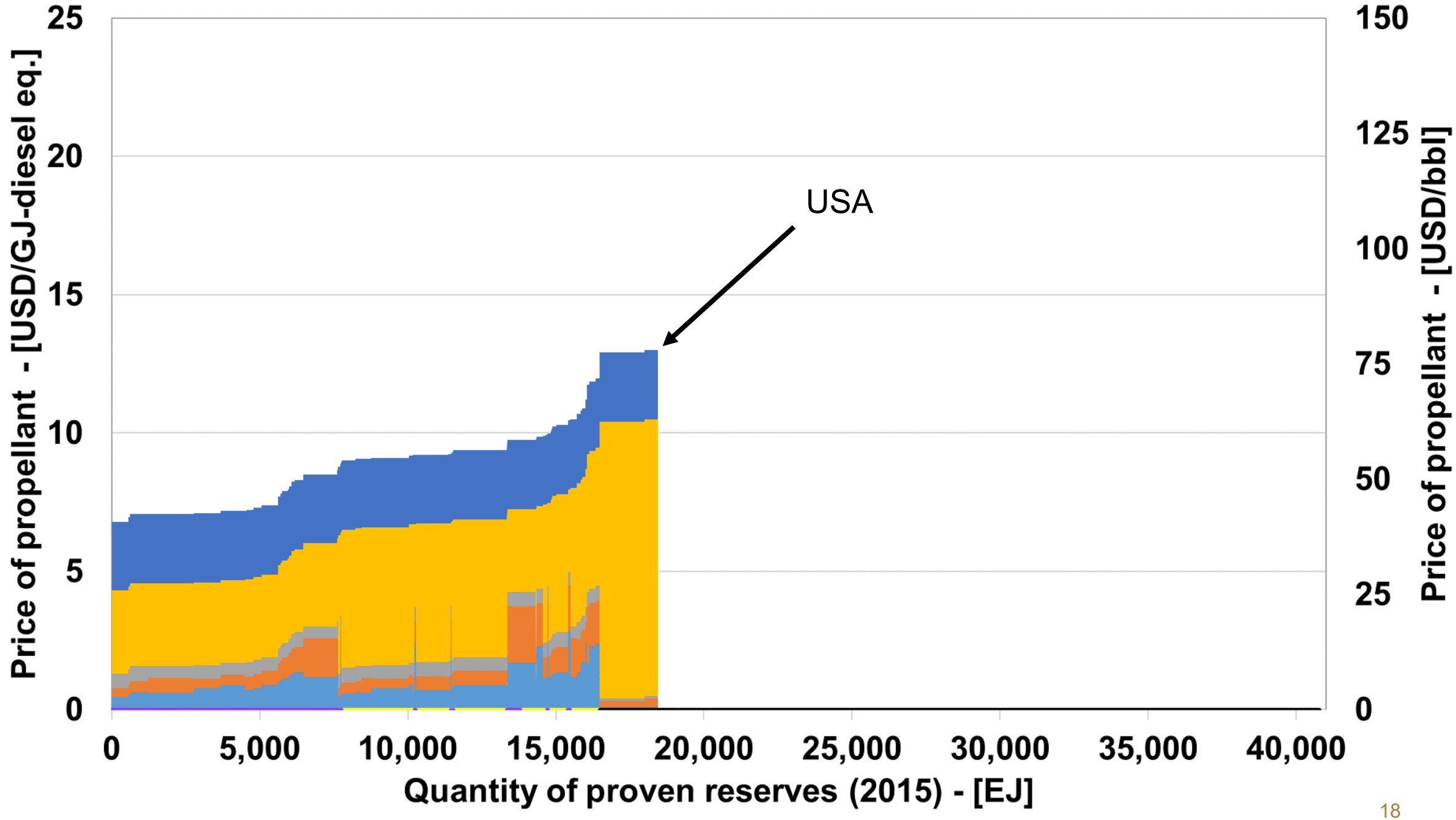
Price of propellant - [USD/GJ-diesel eq.]
25
20
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125
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25
0
Price of propellant - [USD/bbl]
USA
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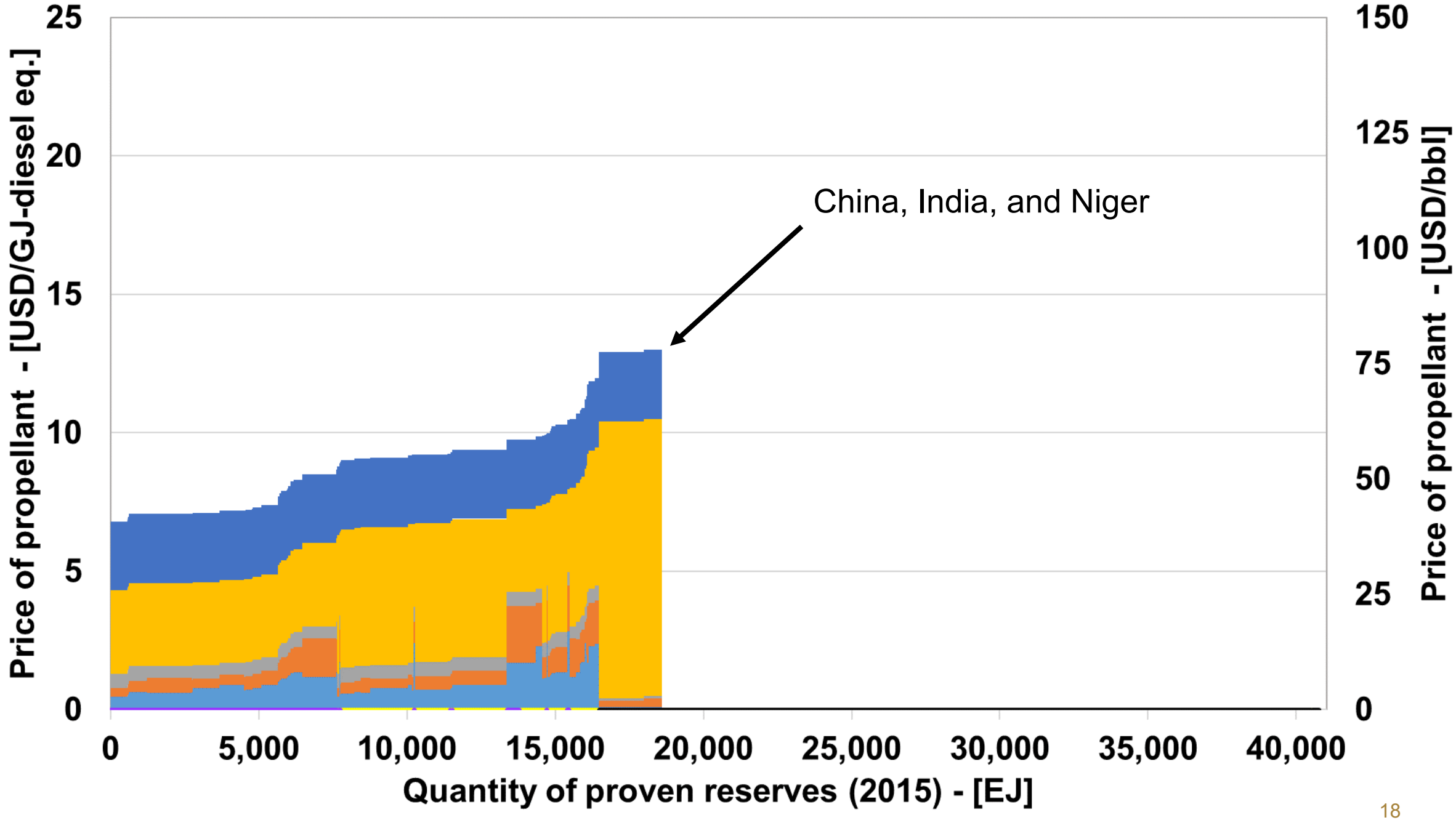
40,000
Quantity of proven reserves (2015) - [EJ]


China, India, and Niger
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
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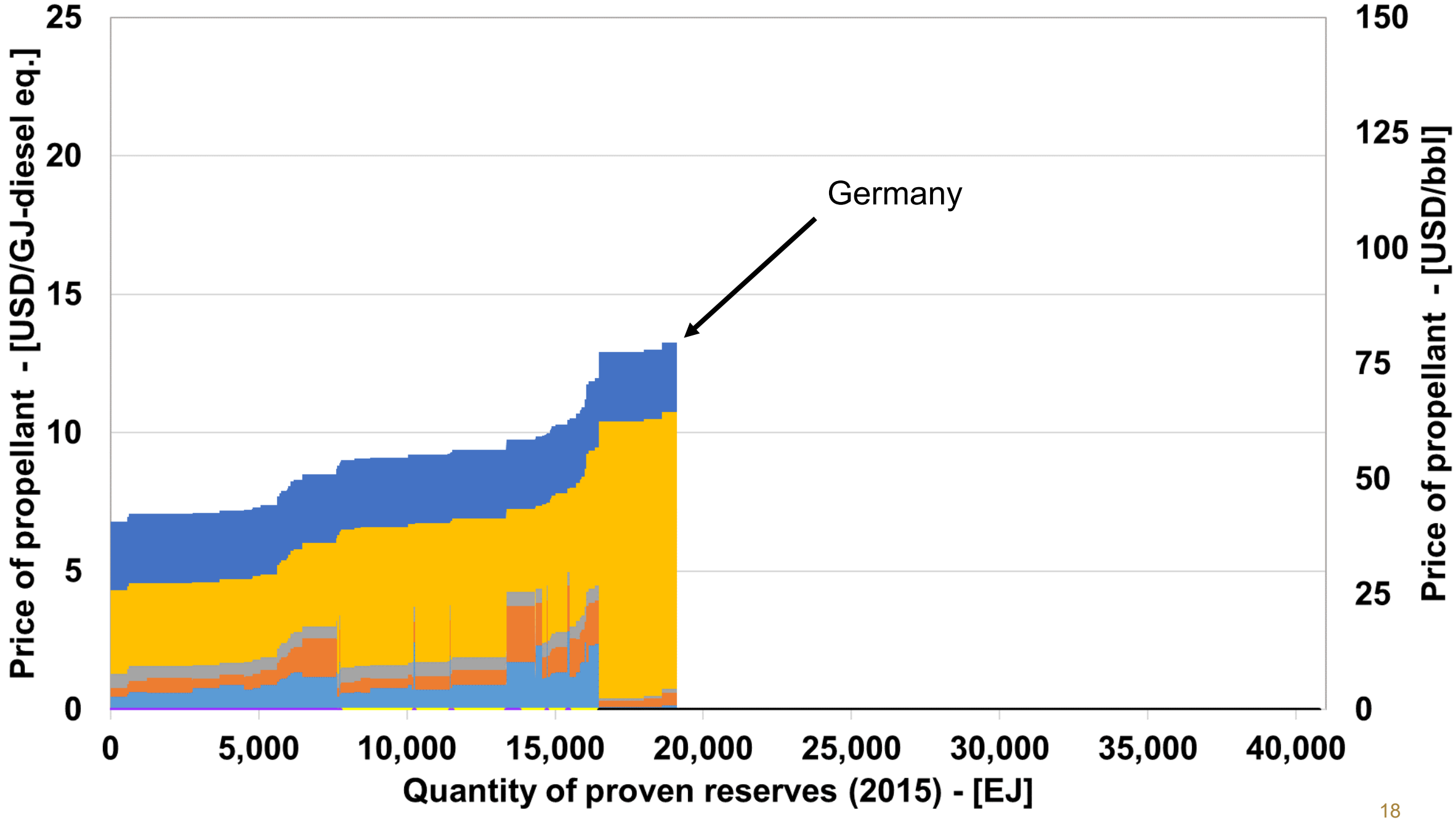
Germany
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
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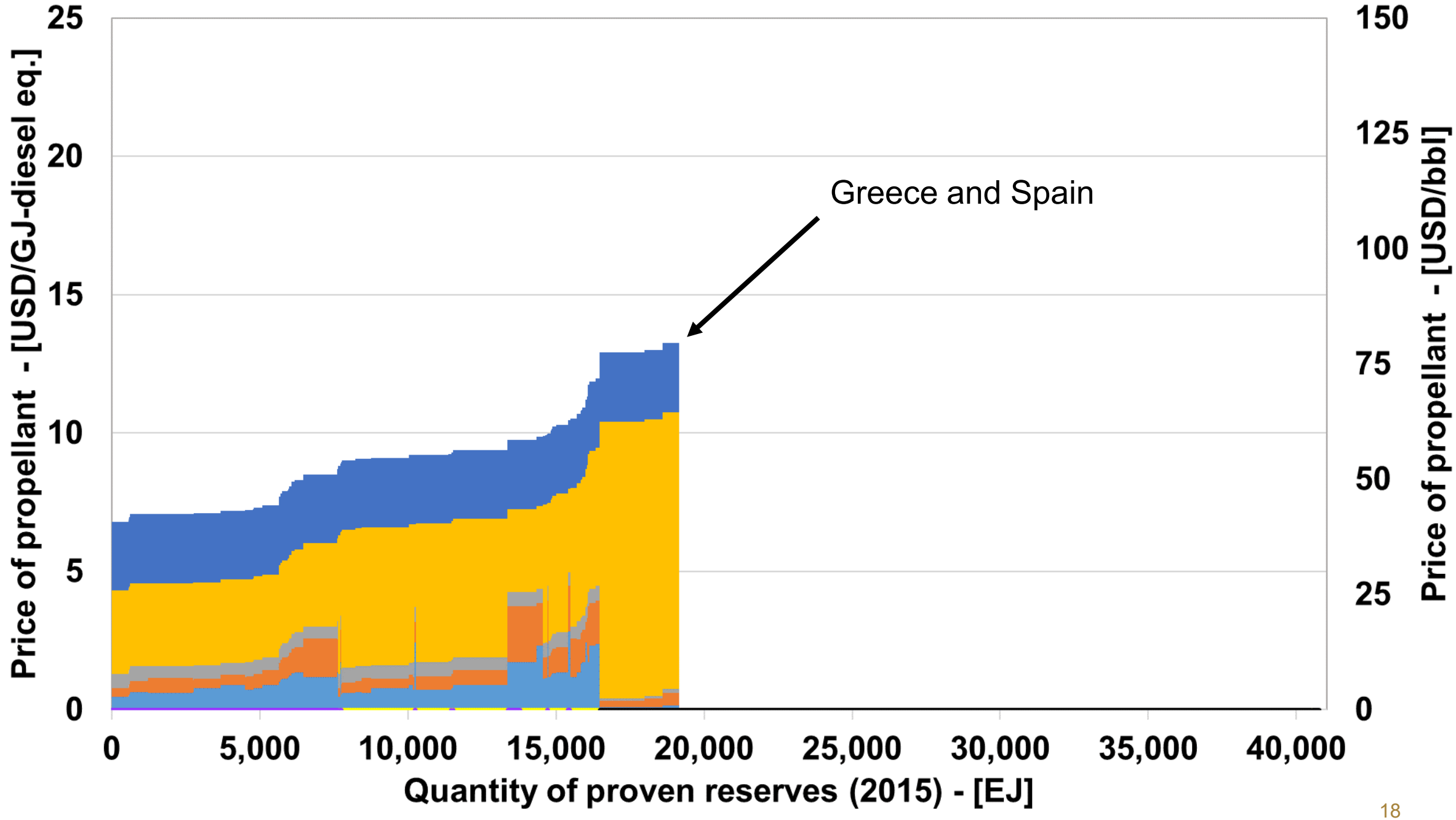
Greece and Spain
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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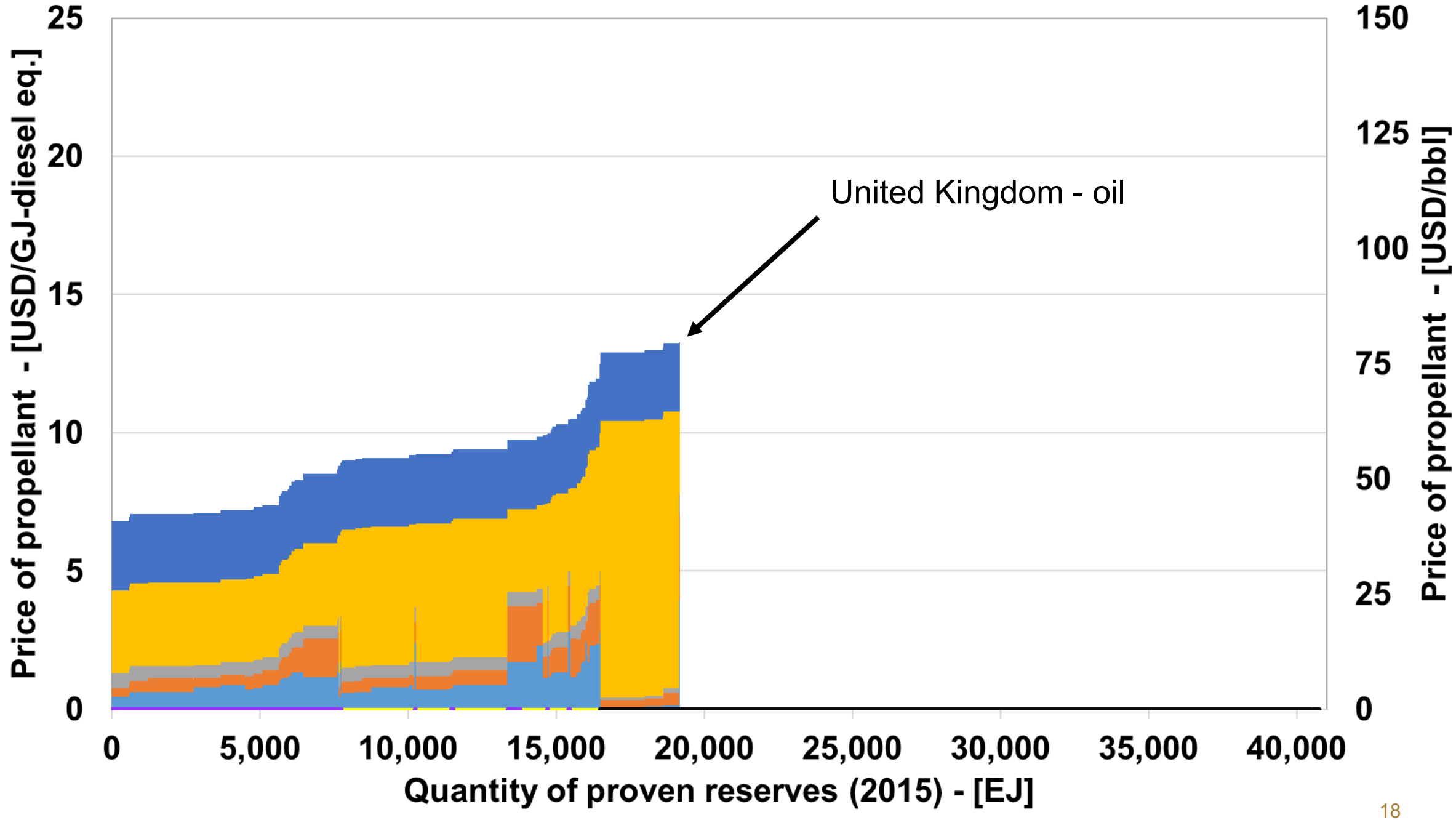
United Kingdom - oil
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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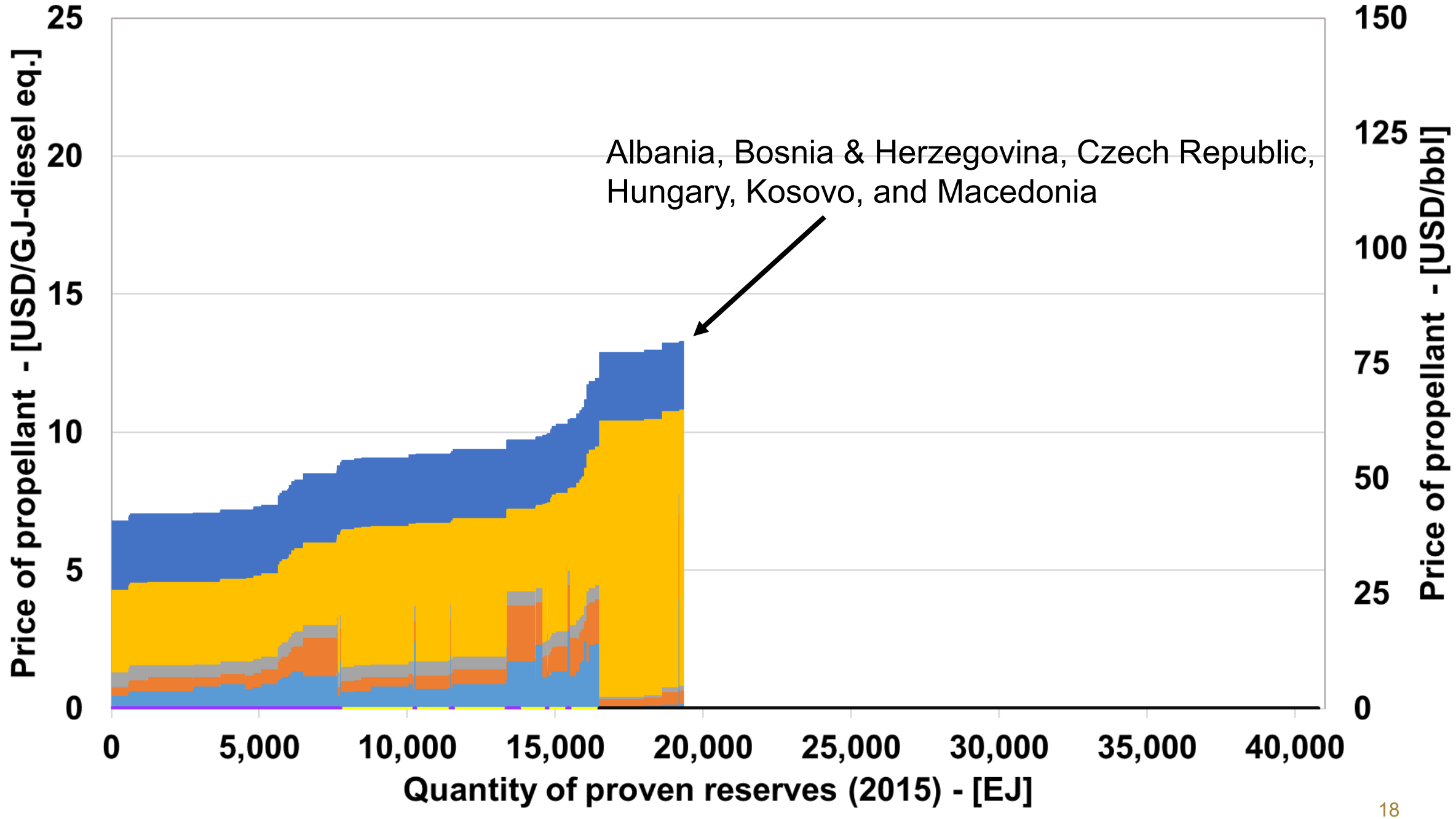
Albania, Bosnia & Herzegovina, Czech Republic, Hungary, Kosovo, and Macedonia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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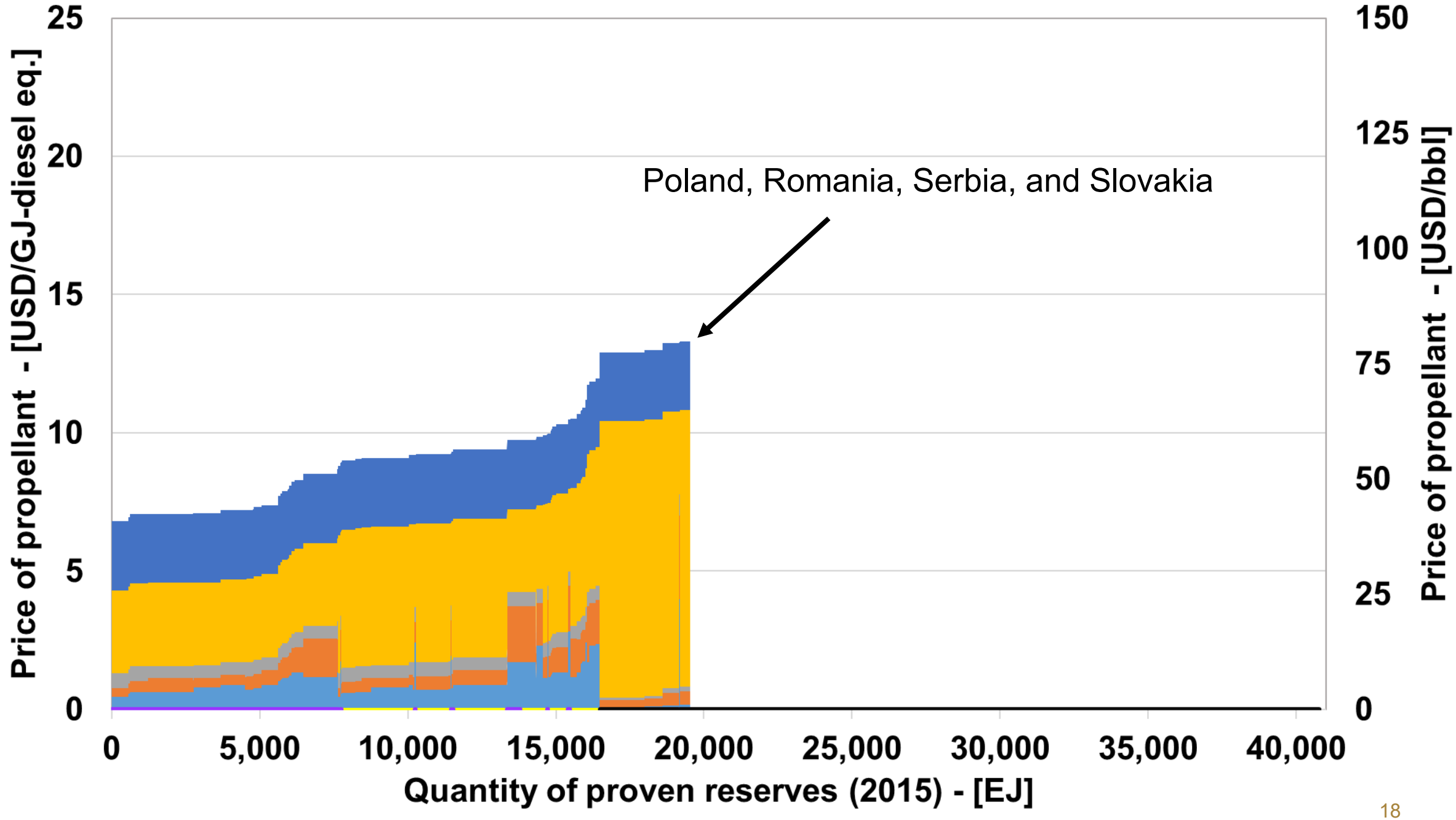
Poland, Romania, Serbia, and Slovakia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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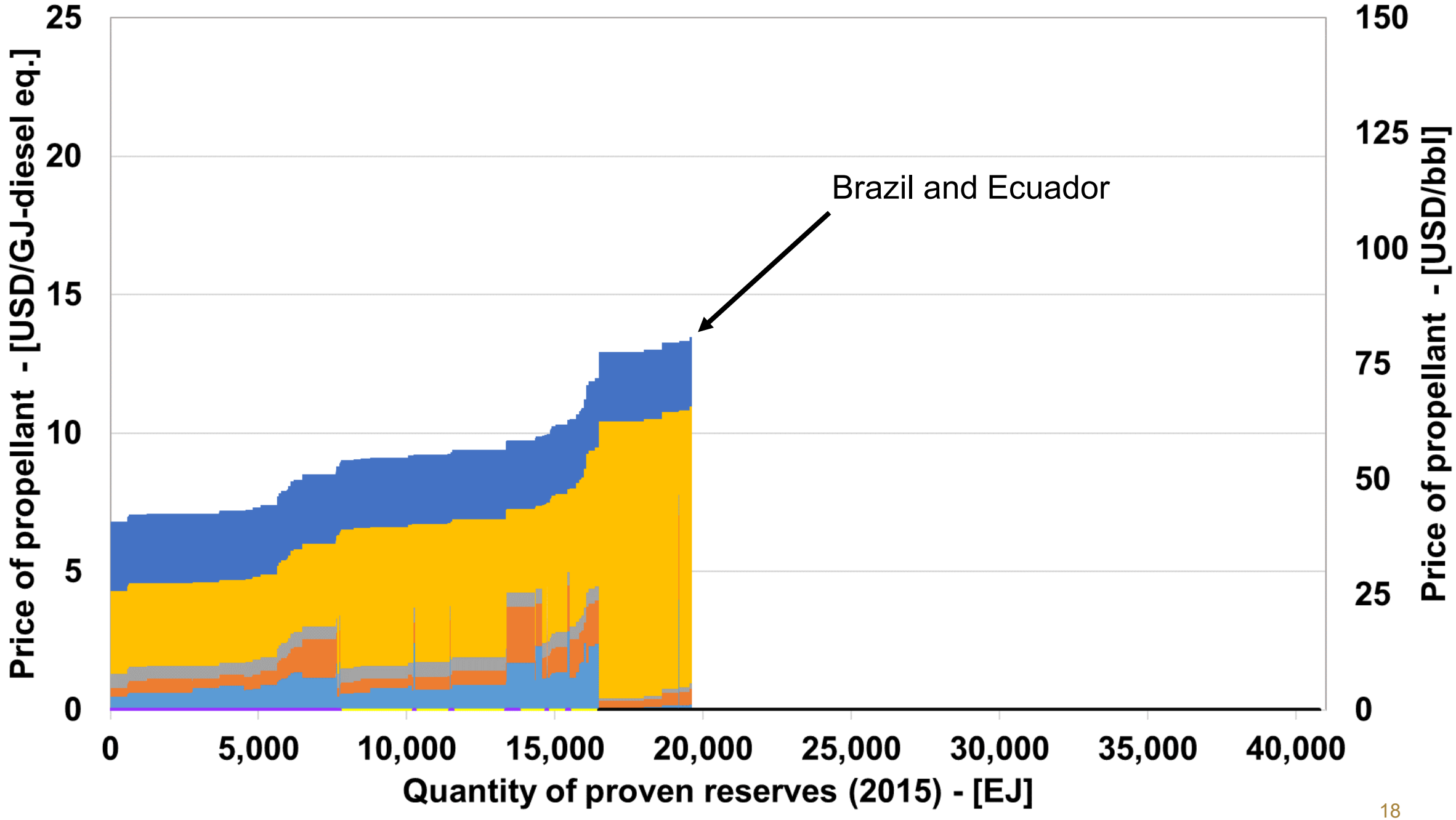
Brazil and Ecuador
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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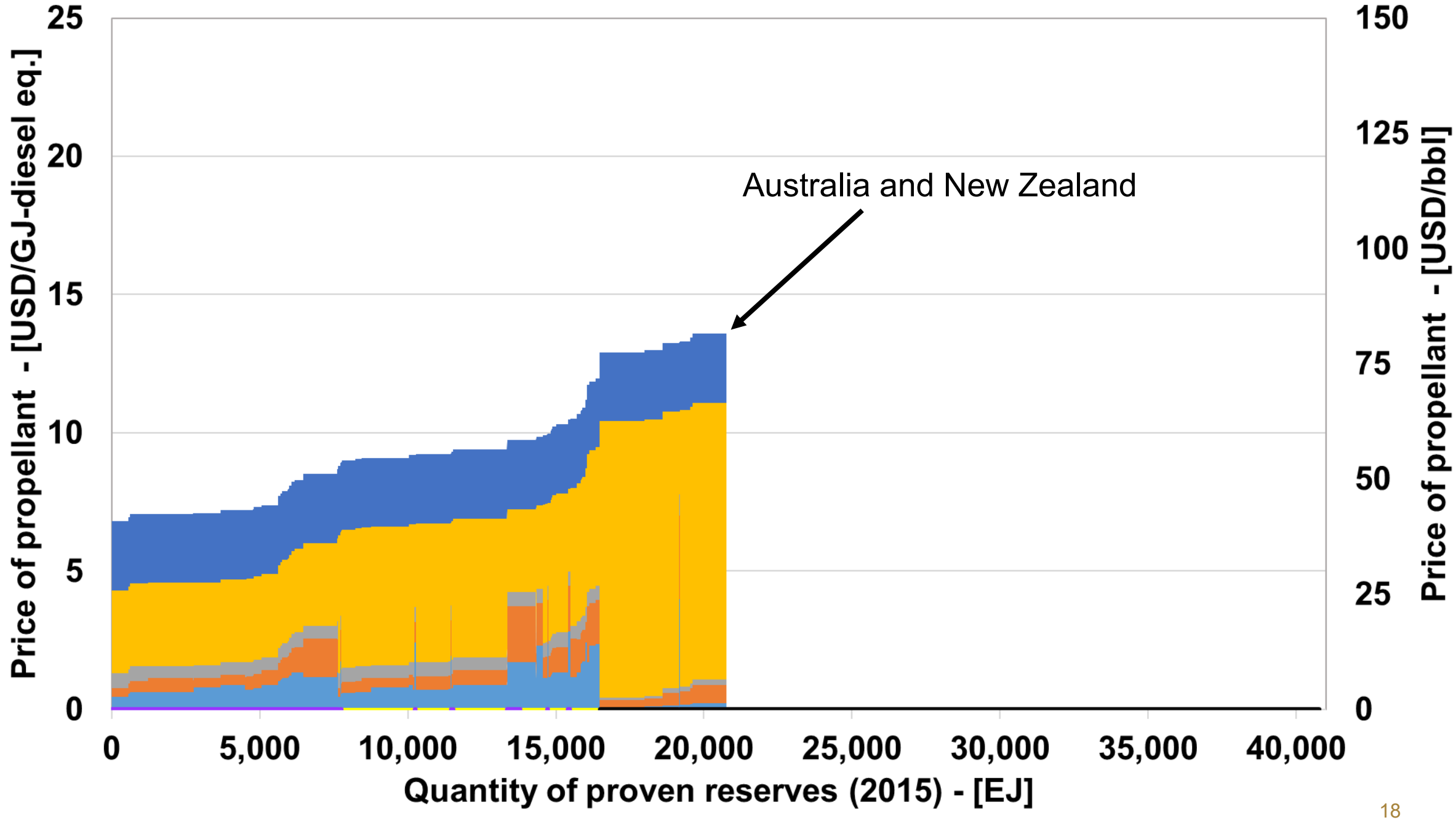
Australia and New Zealand
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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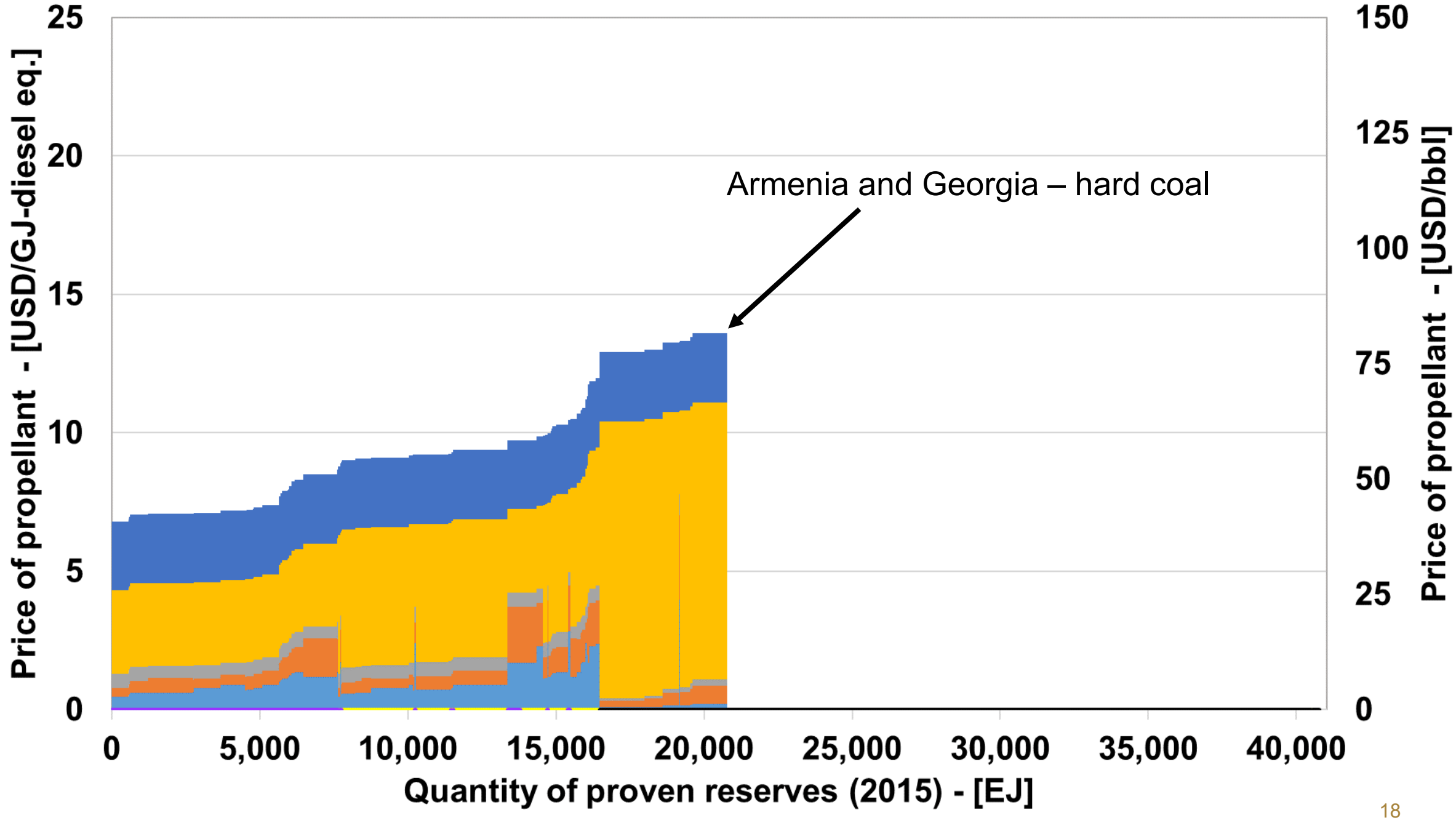
Armenia and Georgia – hard coal
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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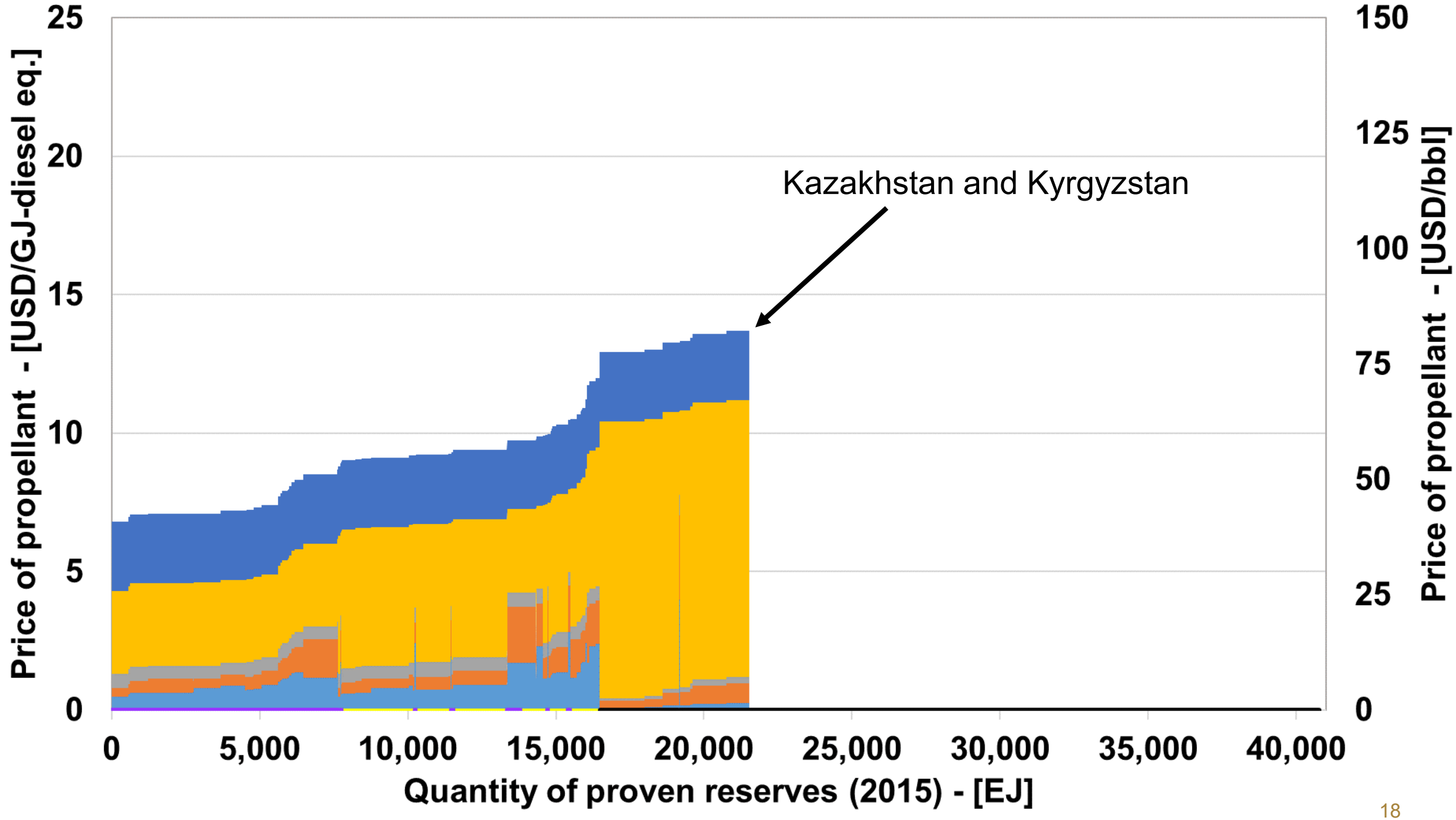
Kazakhstan and Kyrgyzstan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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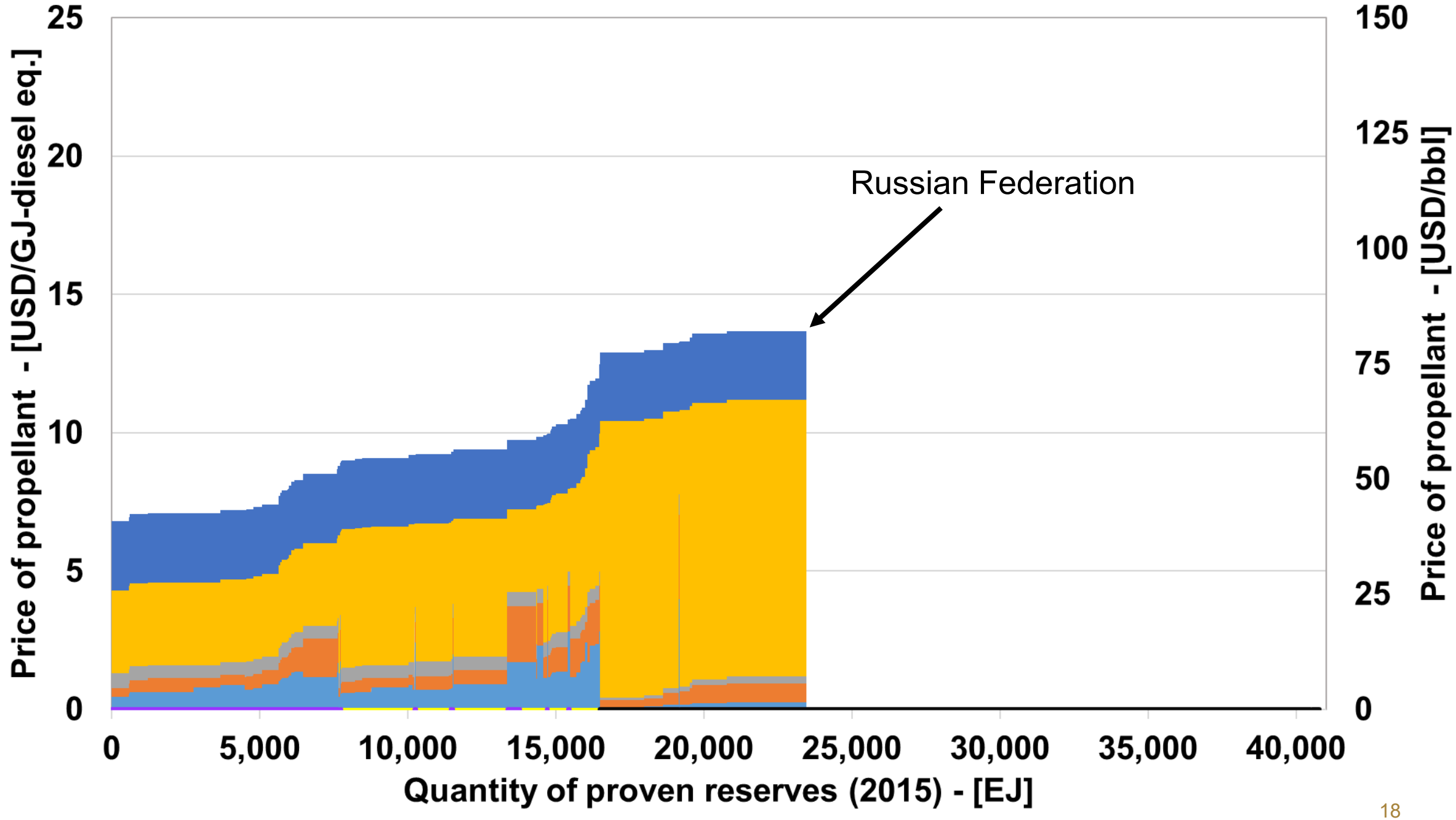
Russian Federation
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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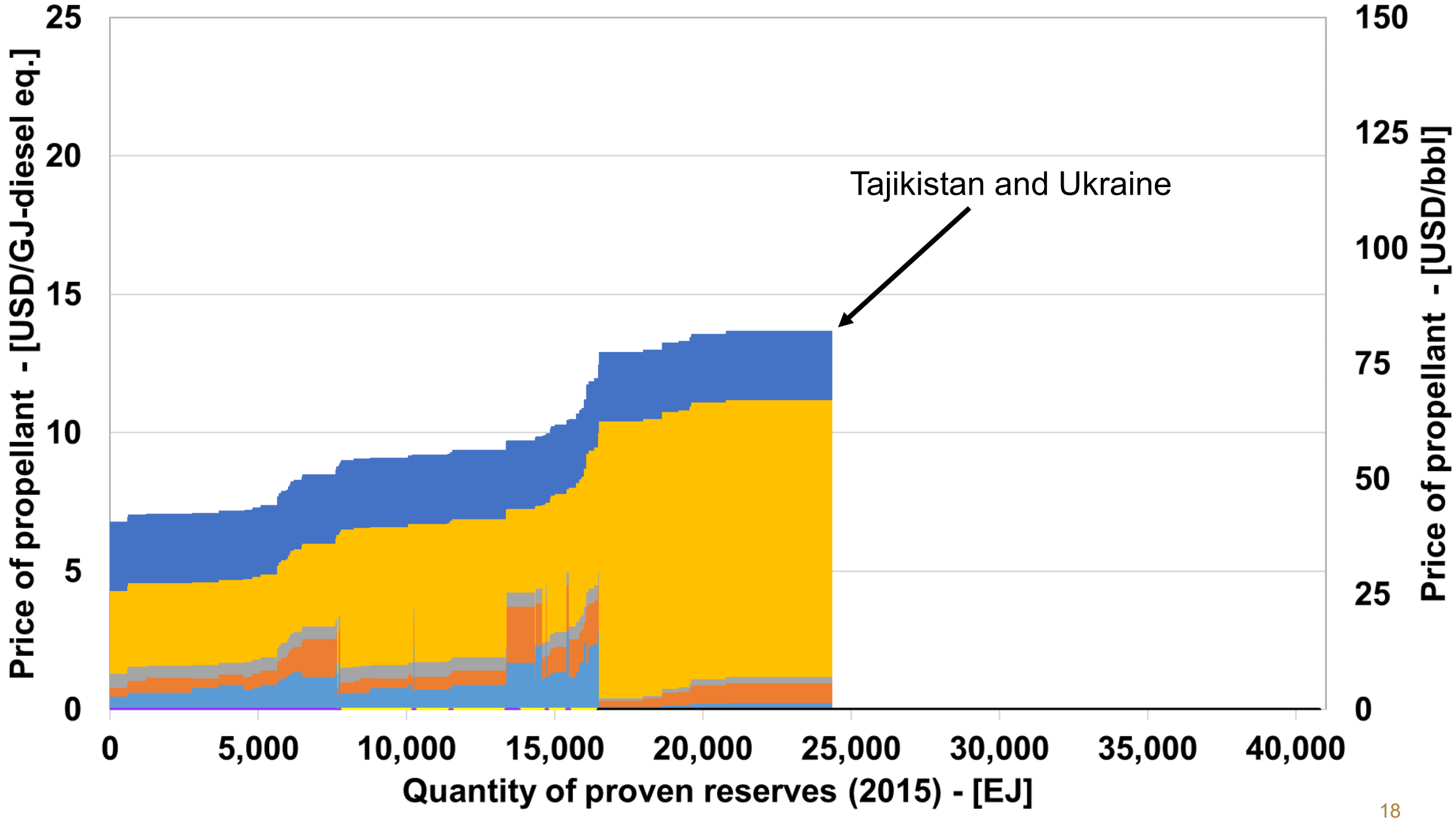
Tajikistan and Ukraine
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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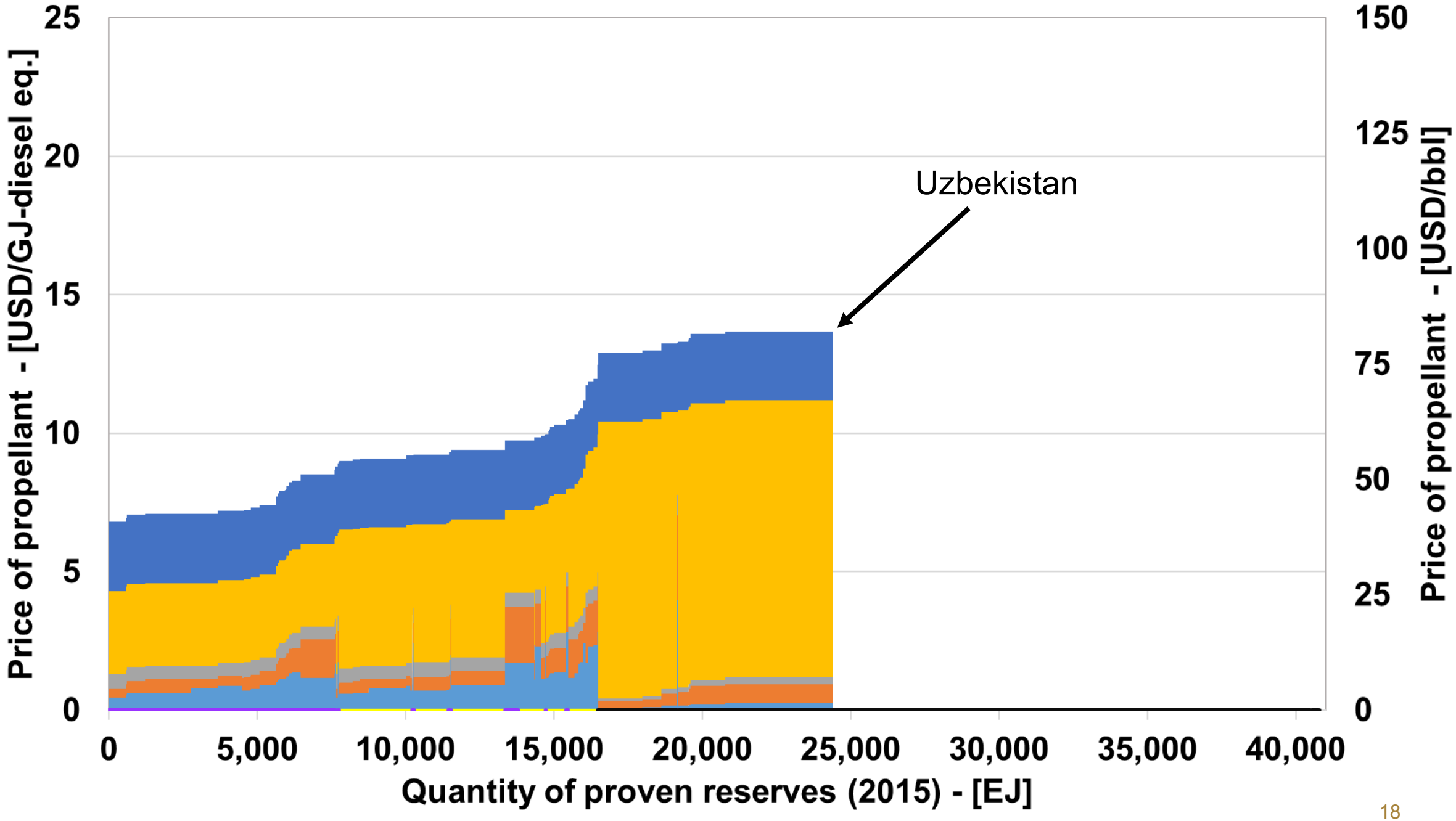
Uzbekistan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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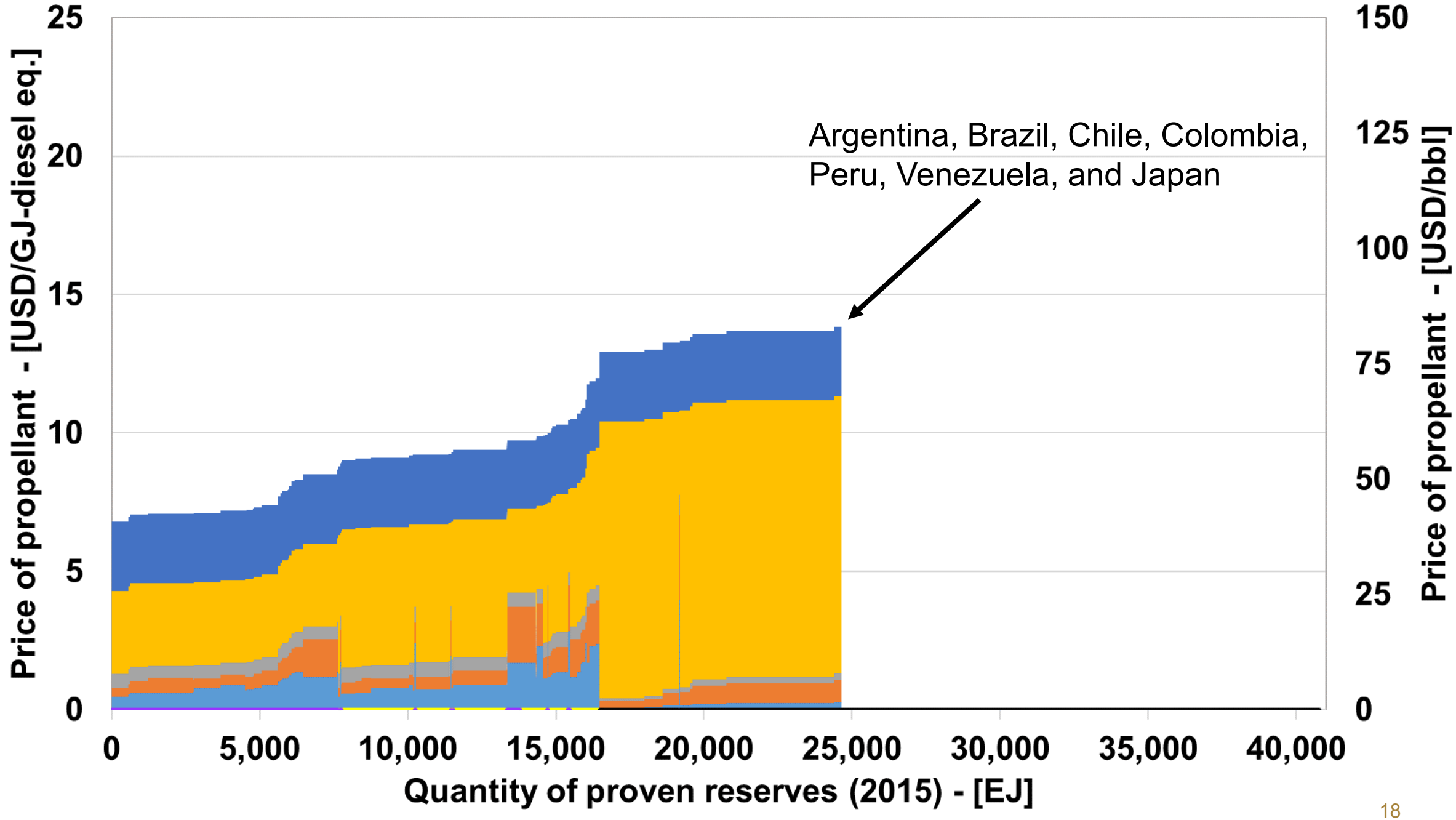
Argentina, Brazil, Chile, Colombia,
Peru, Venezuela, and Japan
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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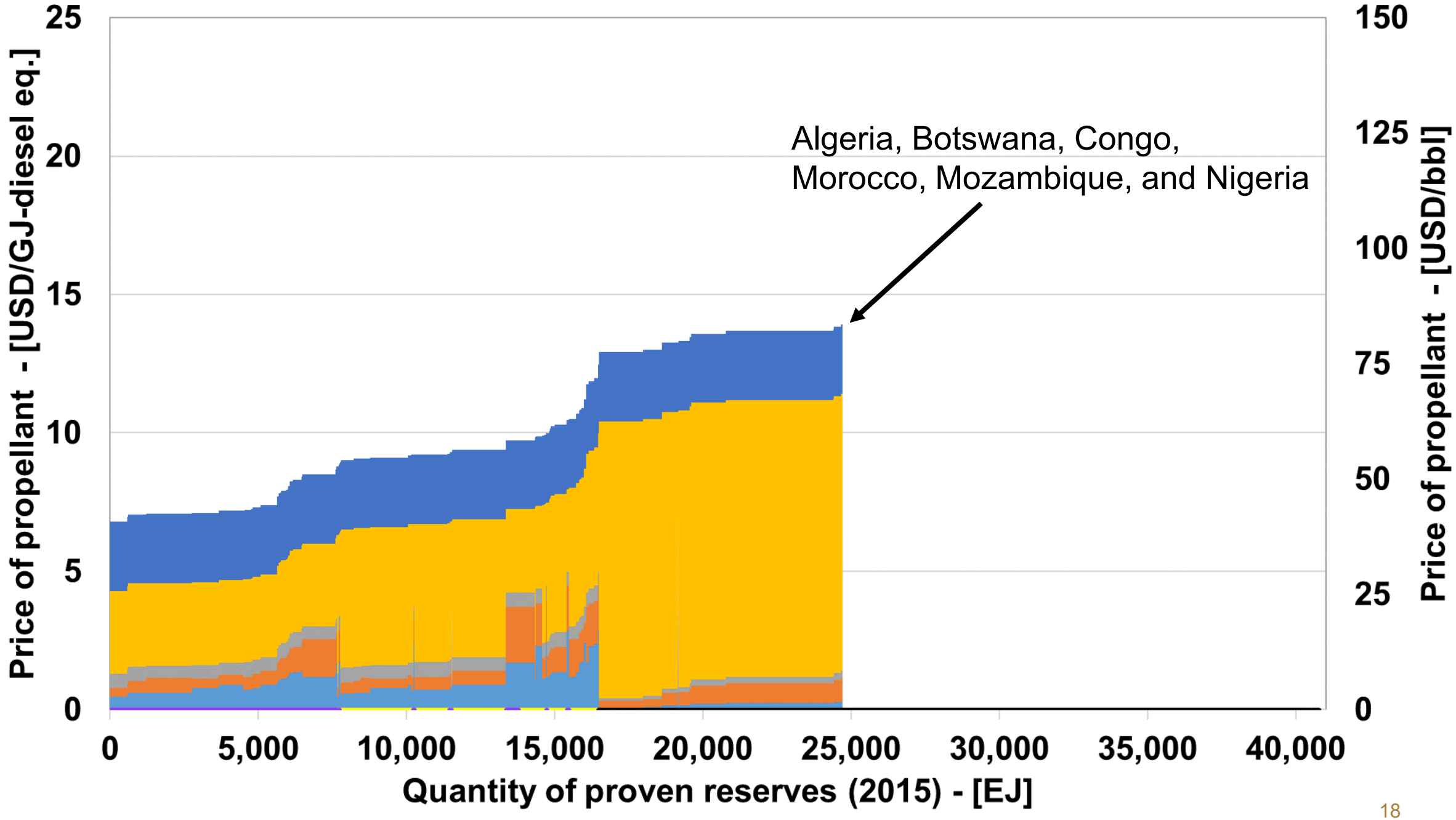
Algeria, Botswana, Congo,
Morocco, Mozambique, and Nigeria
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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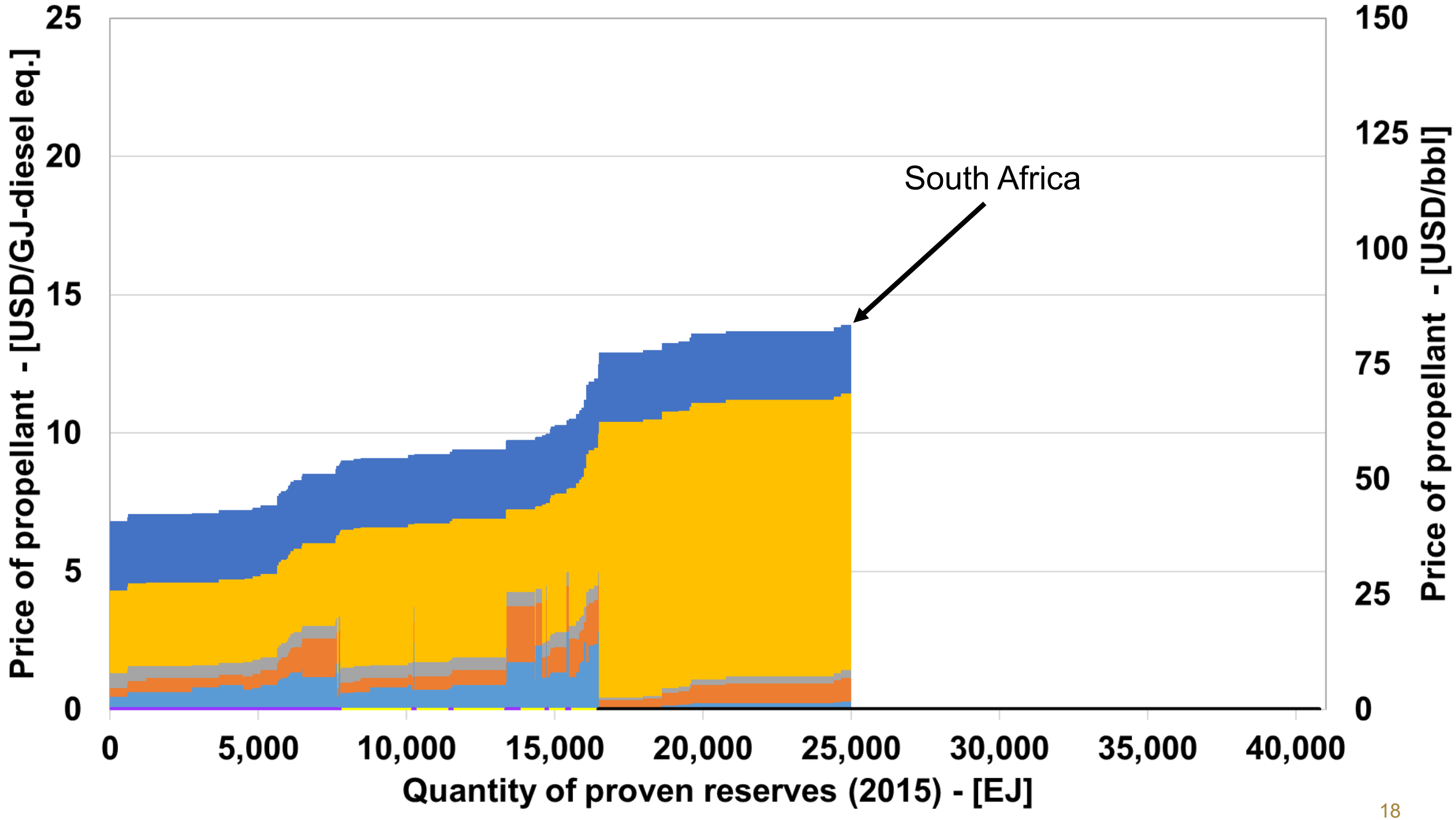
South Africa
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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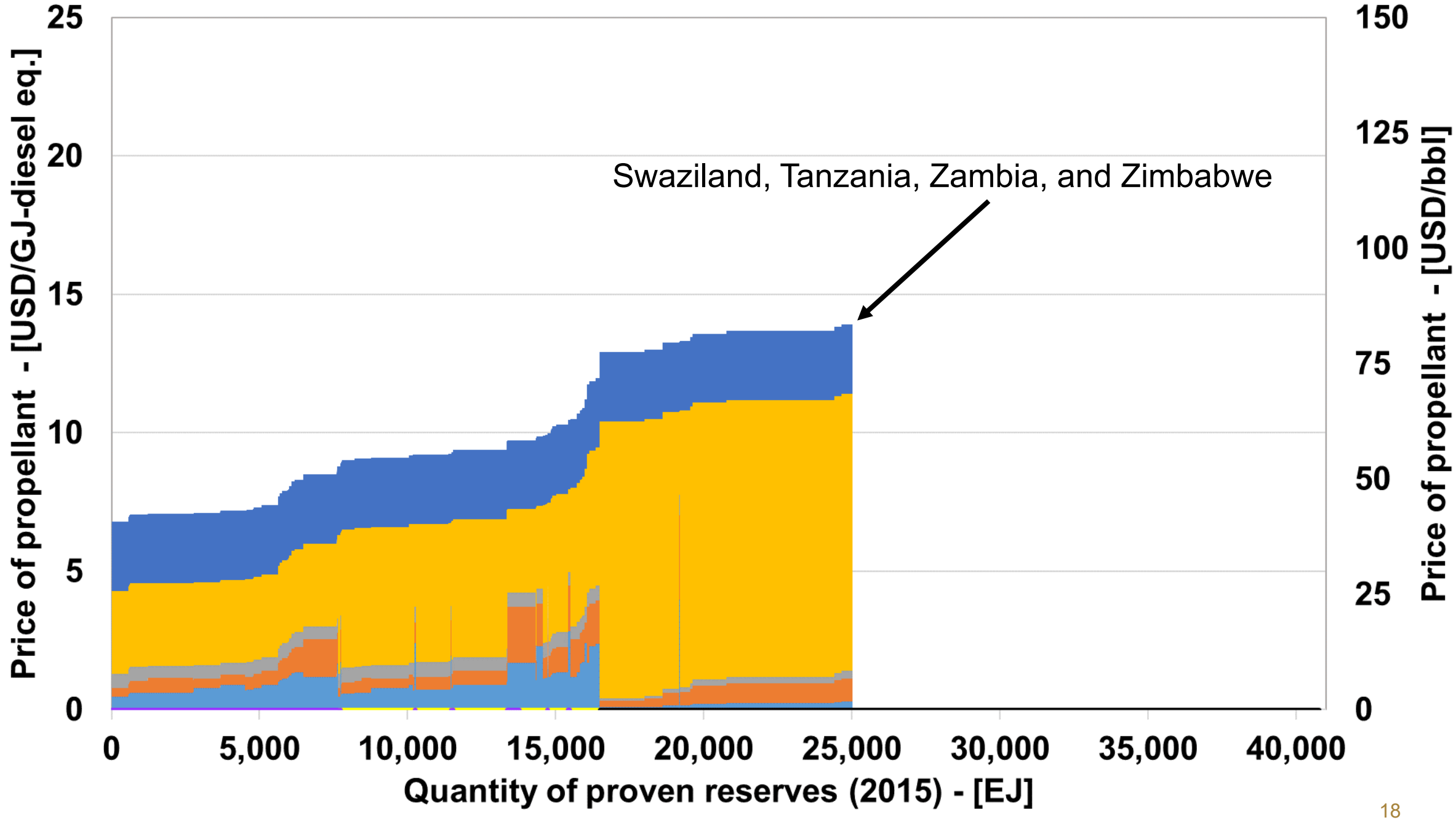
Swaziland, Tanzania, Zambia, and Zimbabwe
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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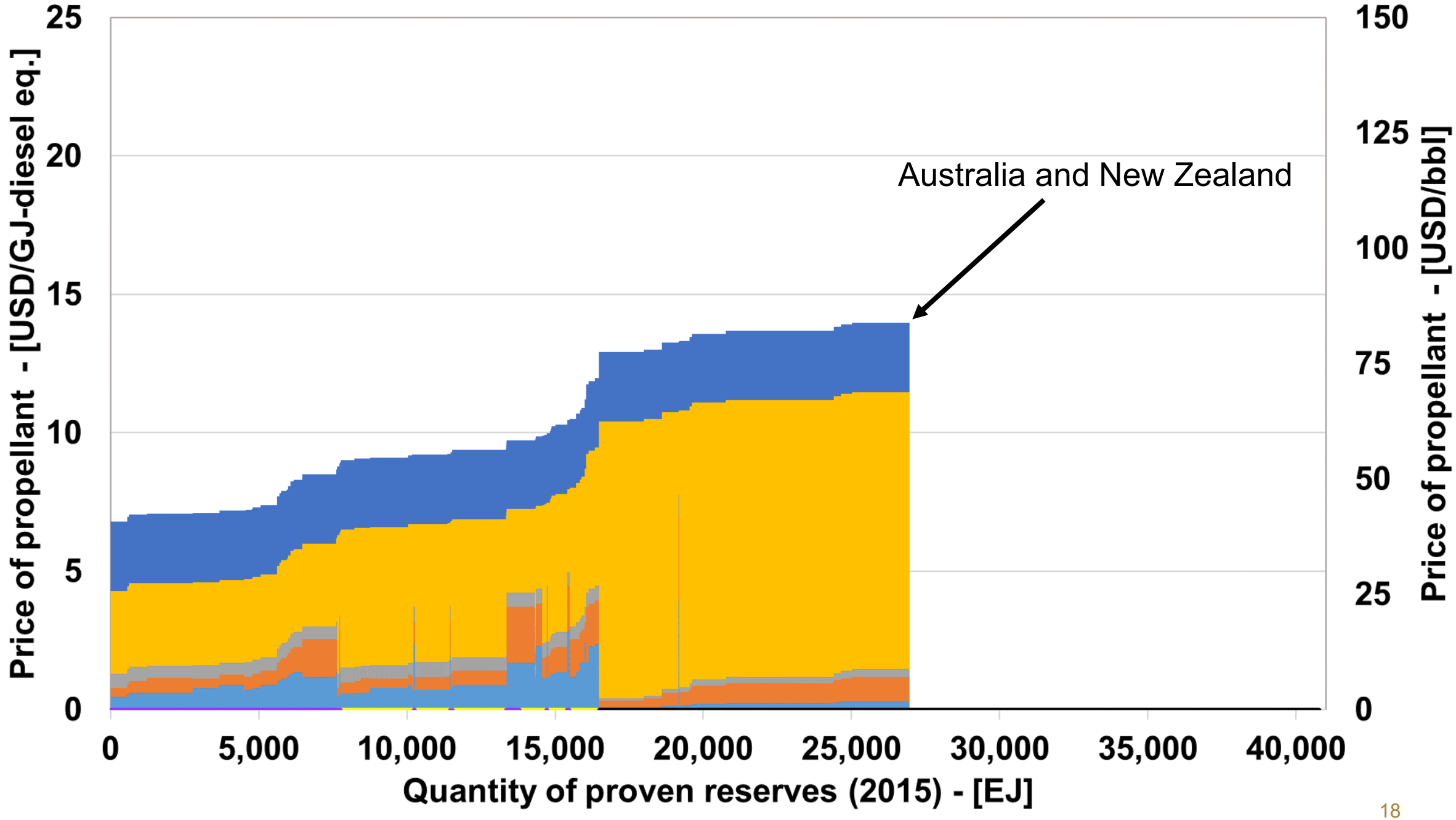
Australia and New Zealand
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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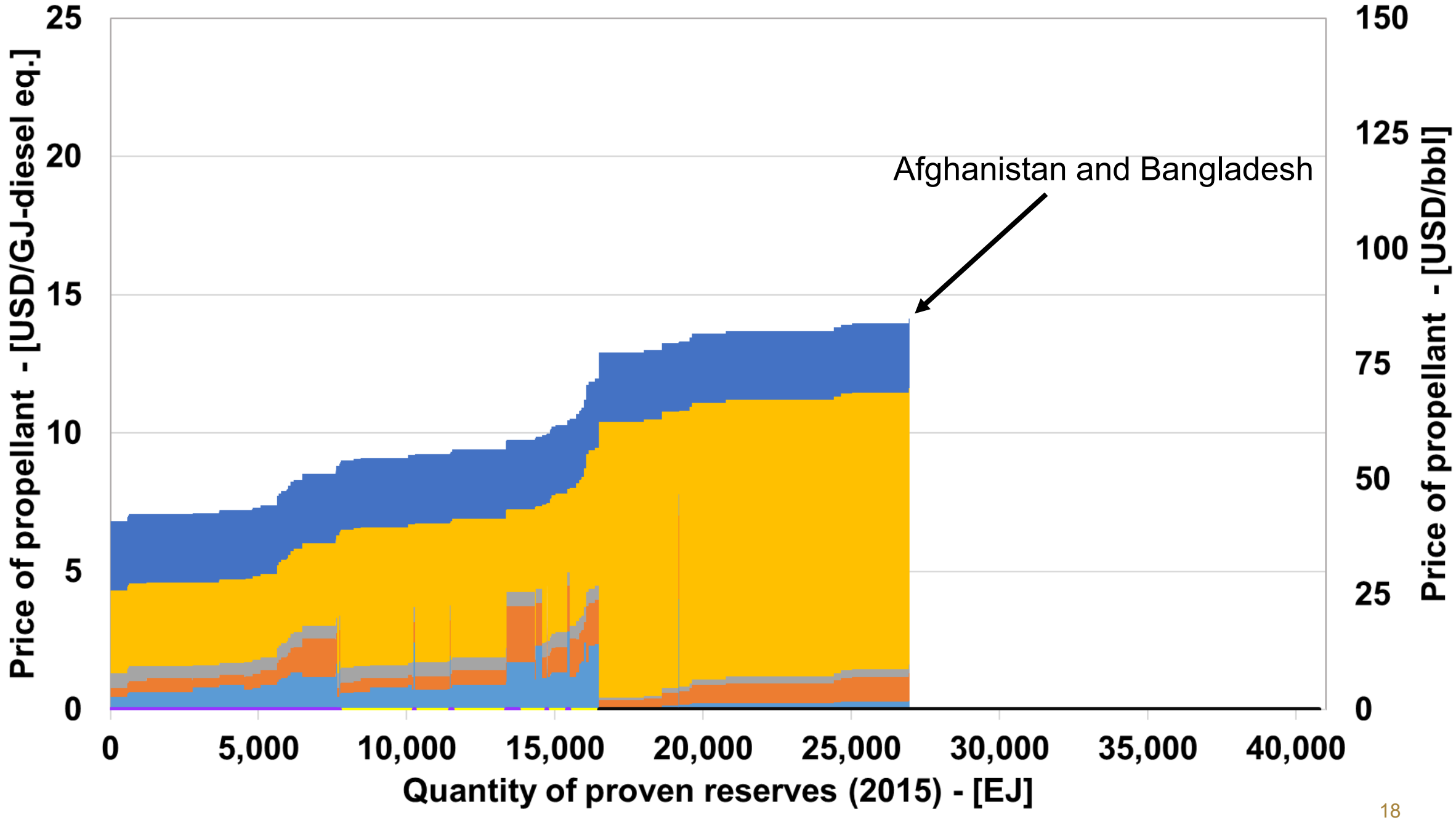
Afghanistan and Bangladesh
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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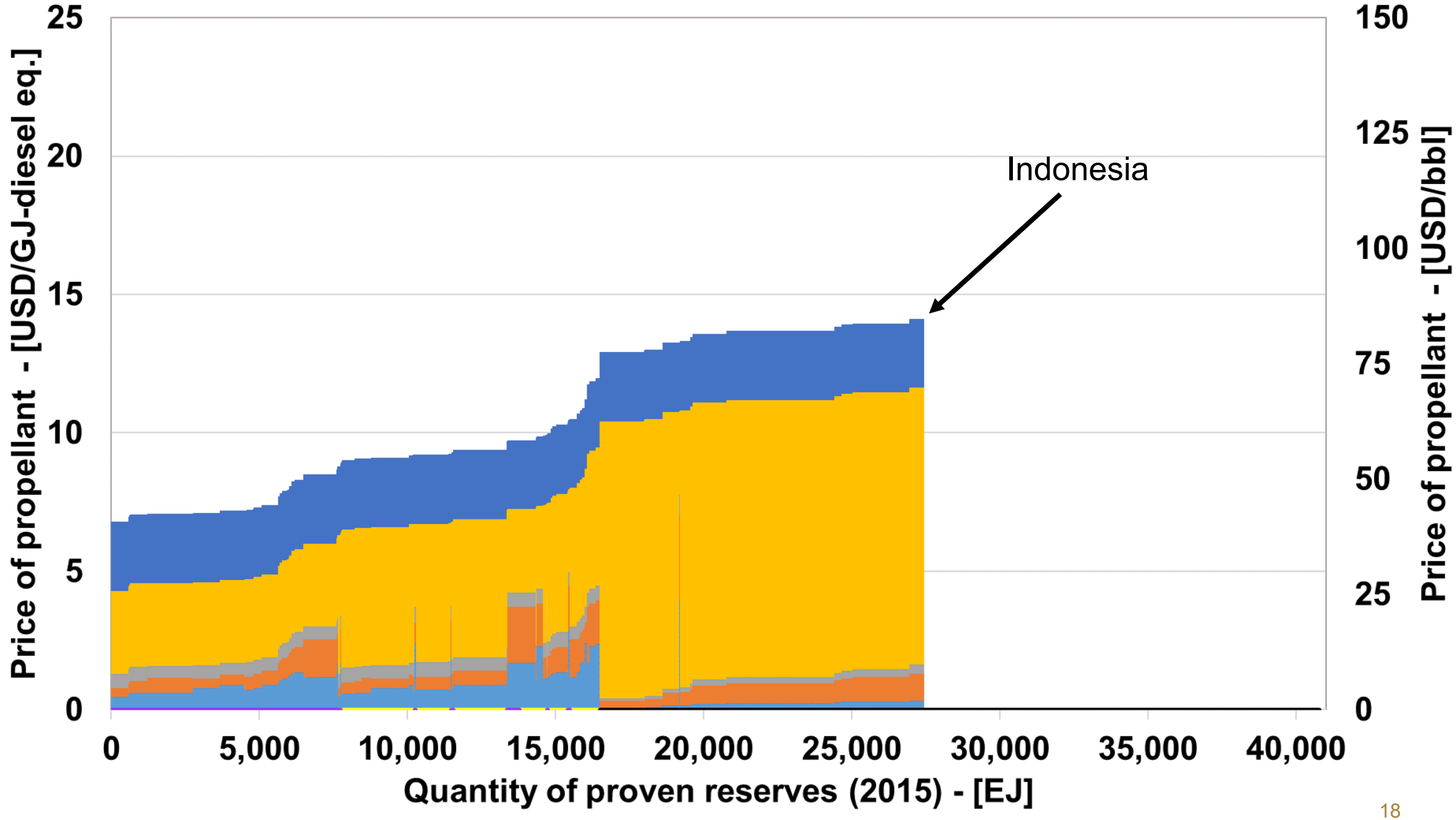
Indonesia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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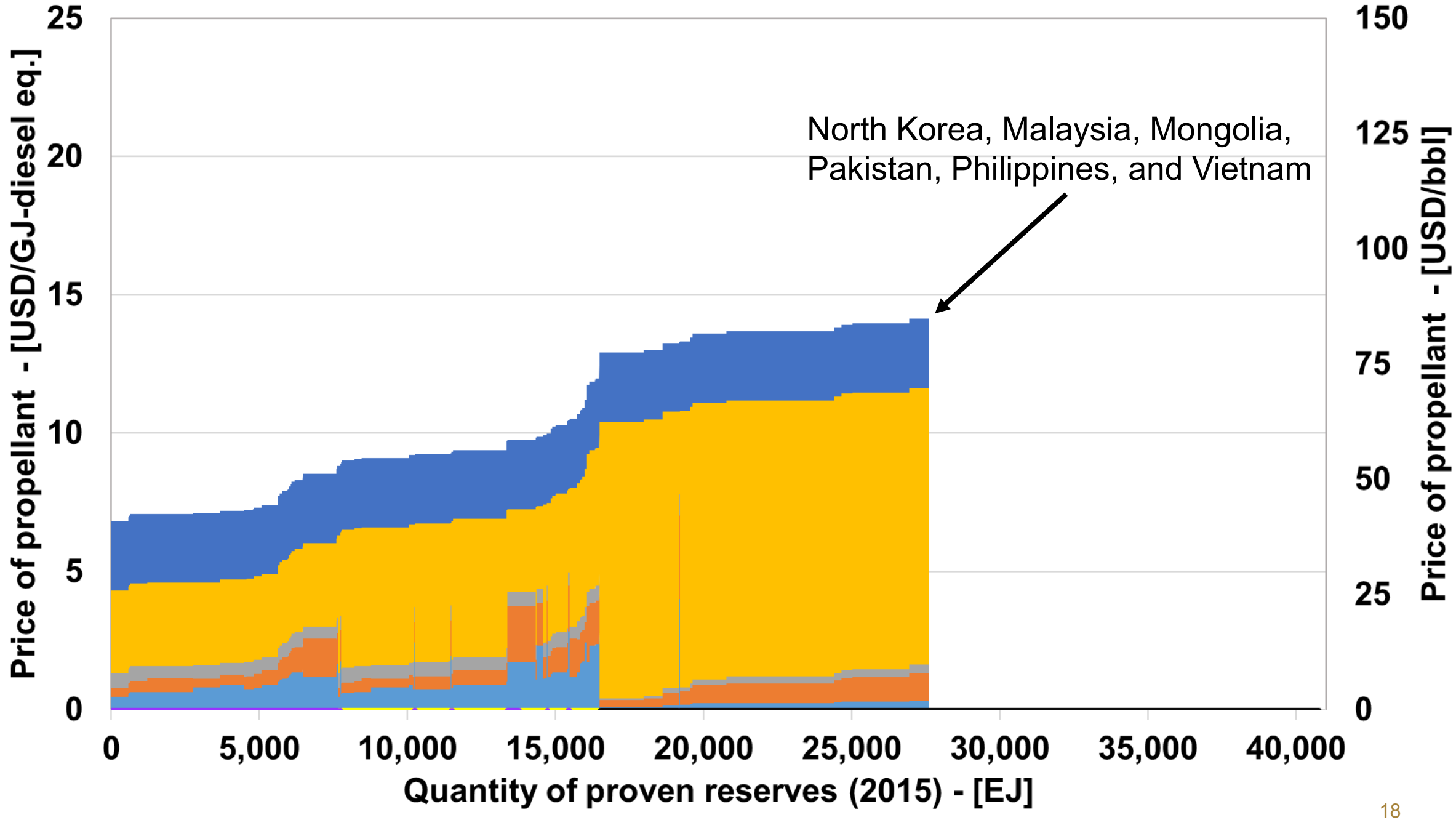
North Korea, Malaysia, Mongolia, Pakistan, Philippines, and Vietnam
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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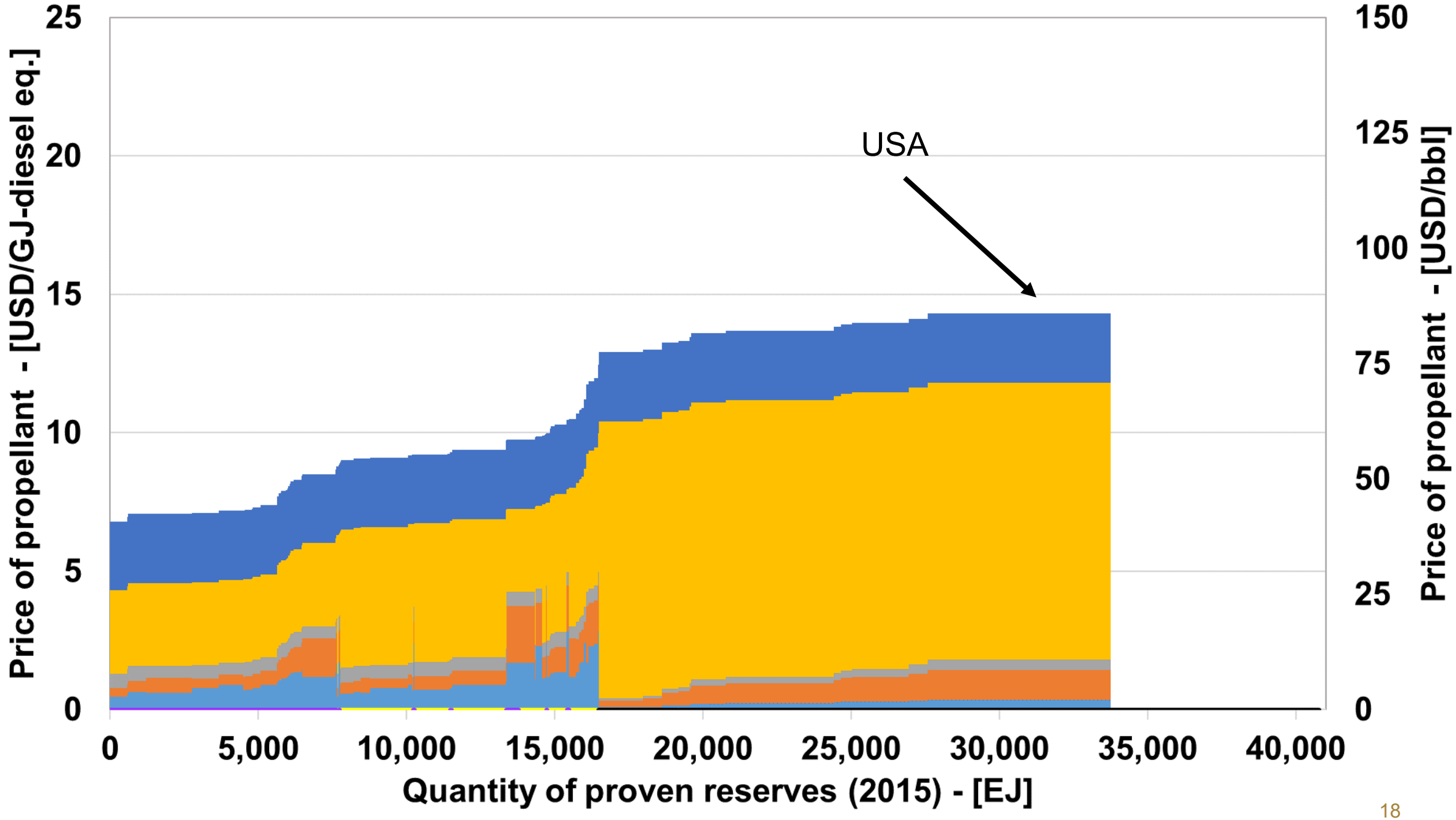
USA
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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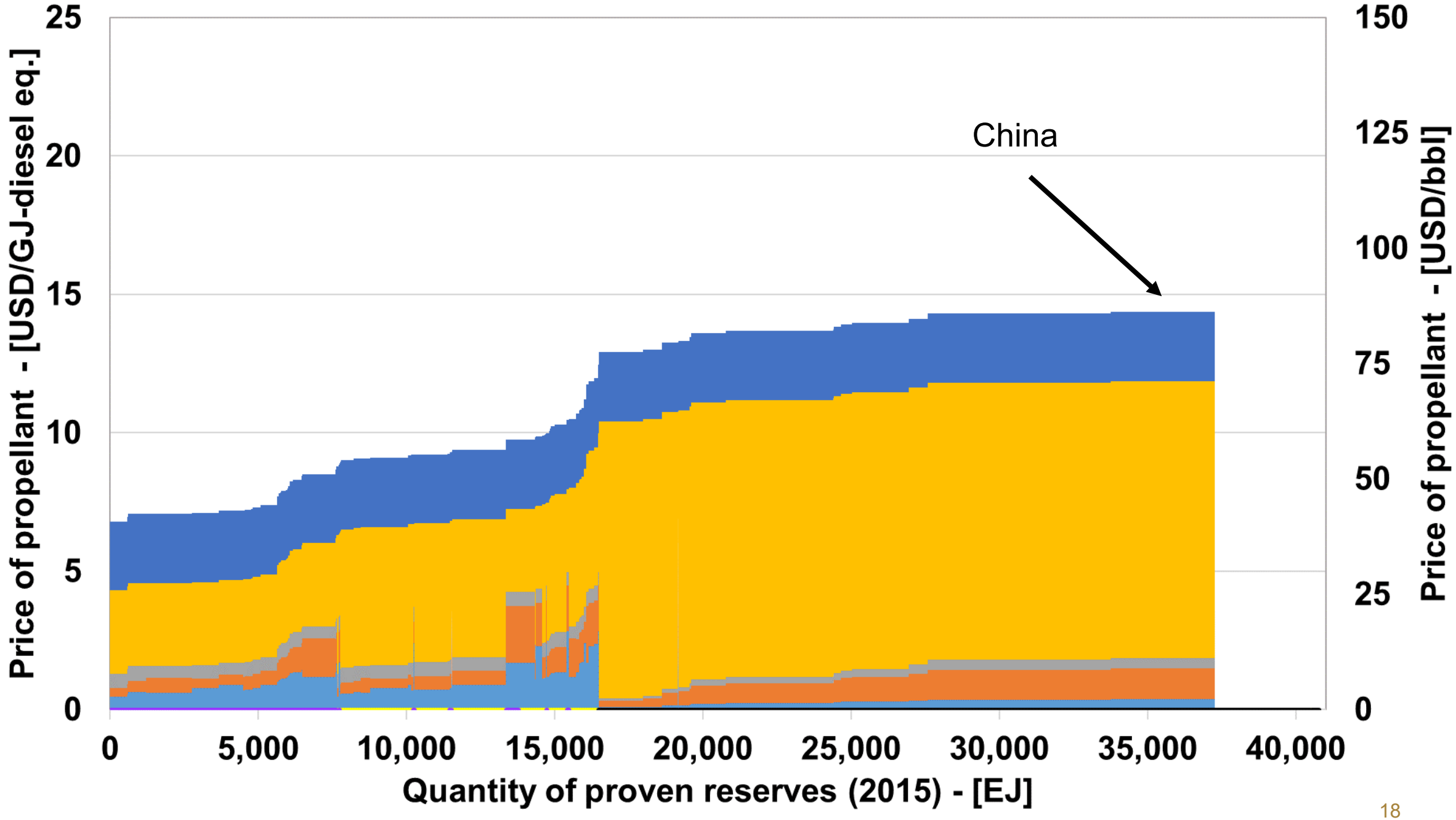
China
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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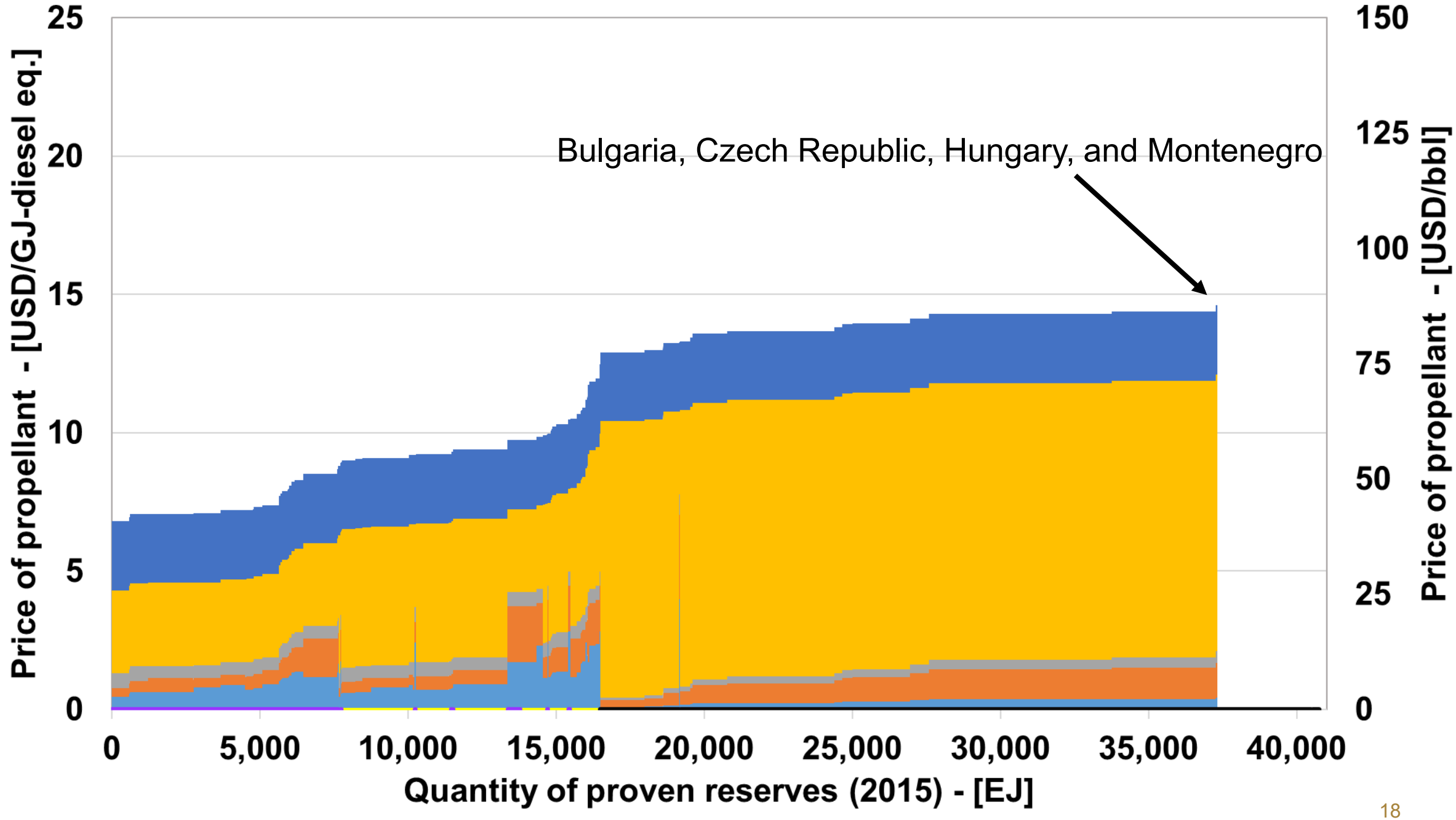
Bulgaria, Czech Republic, Hungary, and Montenegro
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
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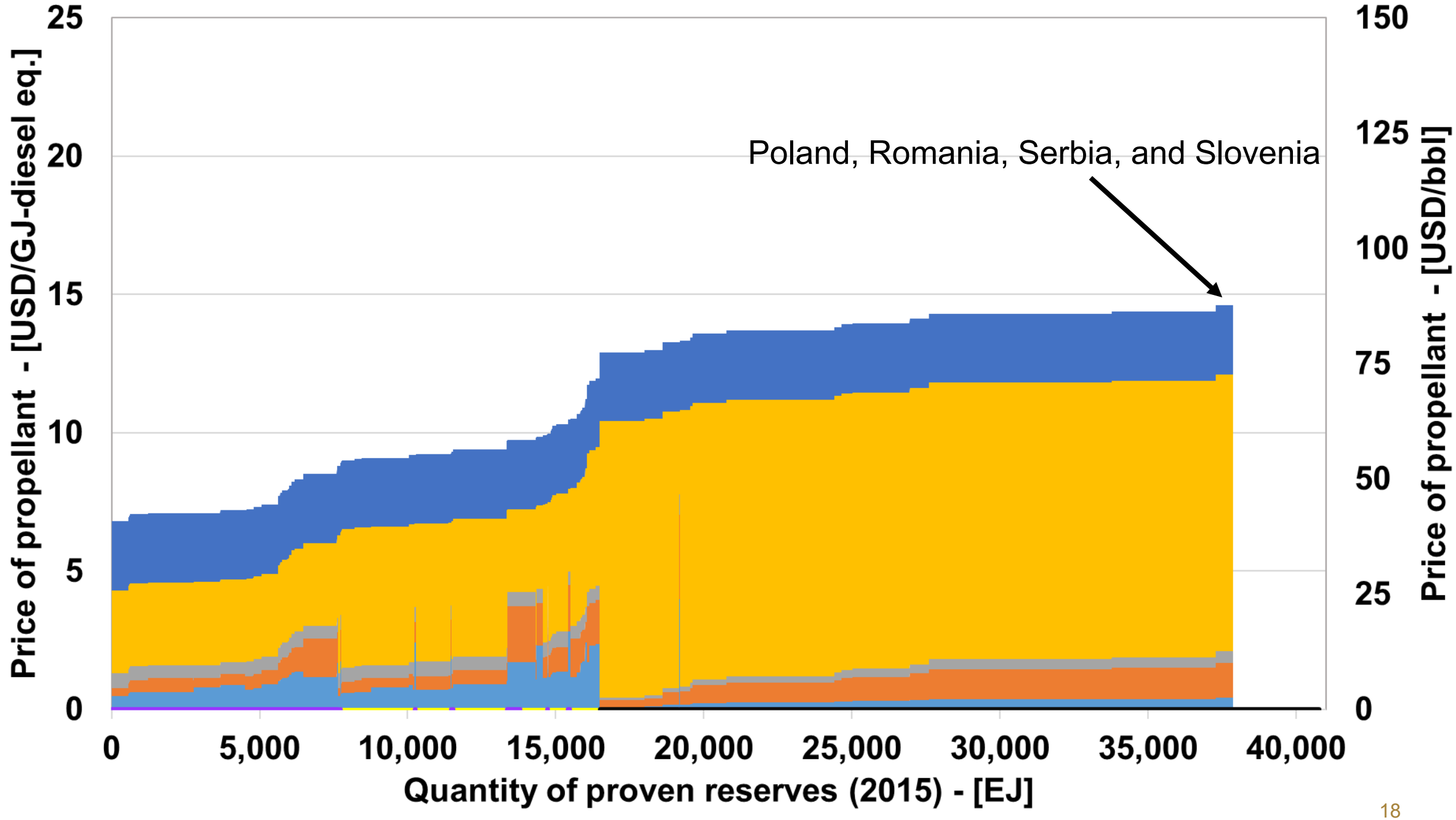
Poland, Romania, Serbia, and Slovenia
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
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125
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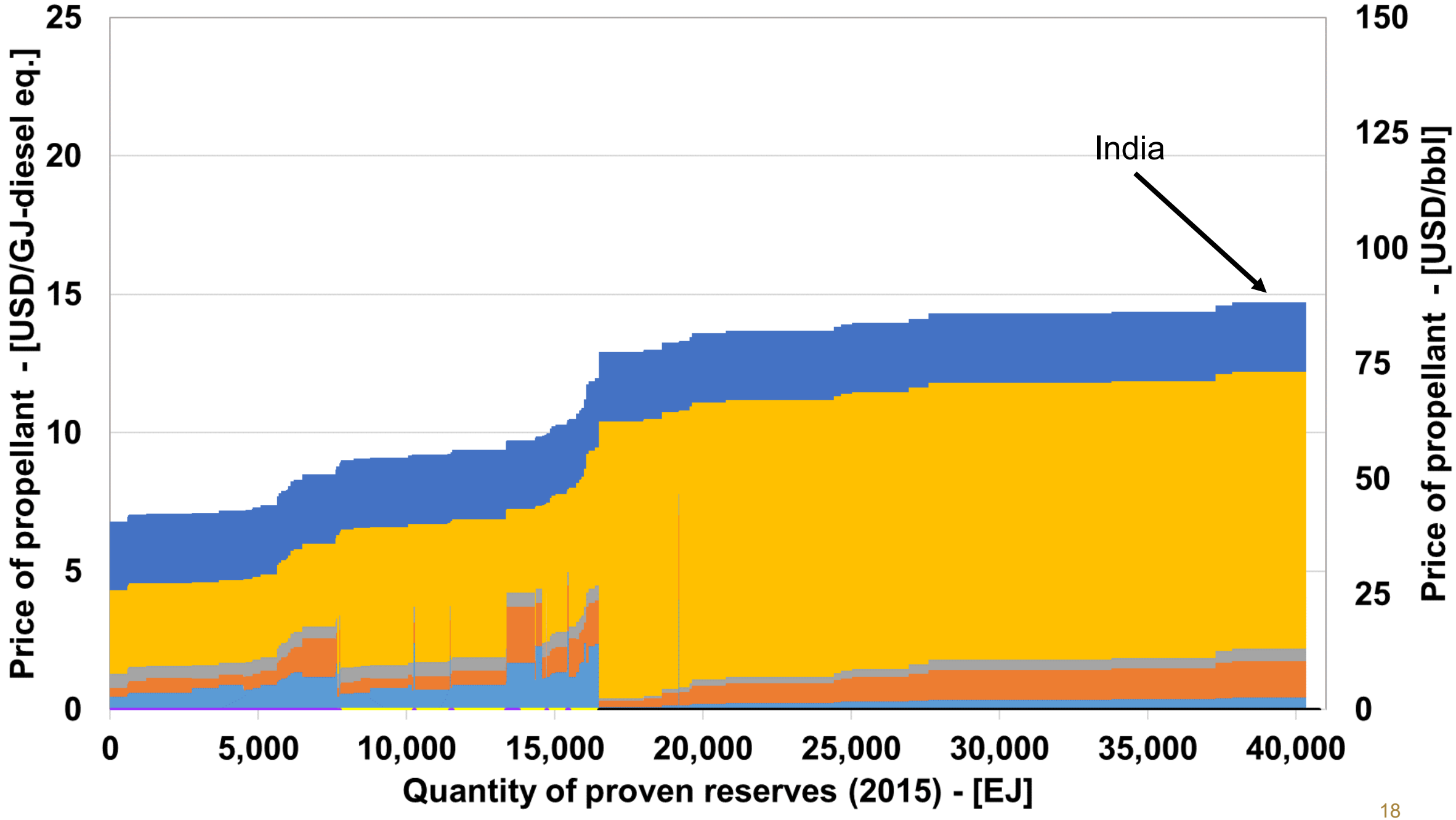
India
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
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35,000
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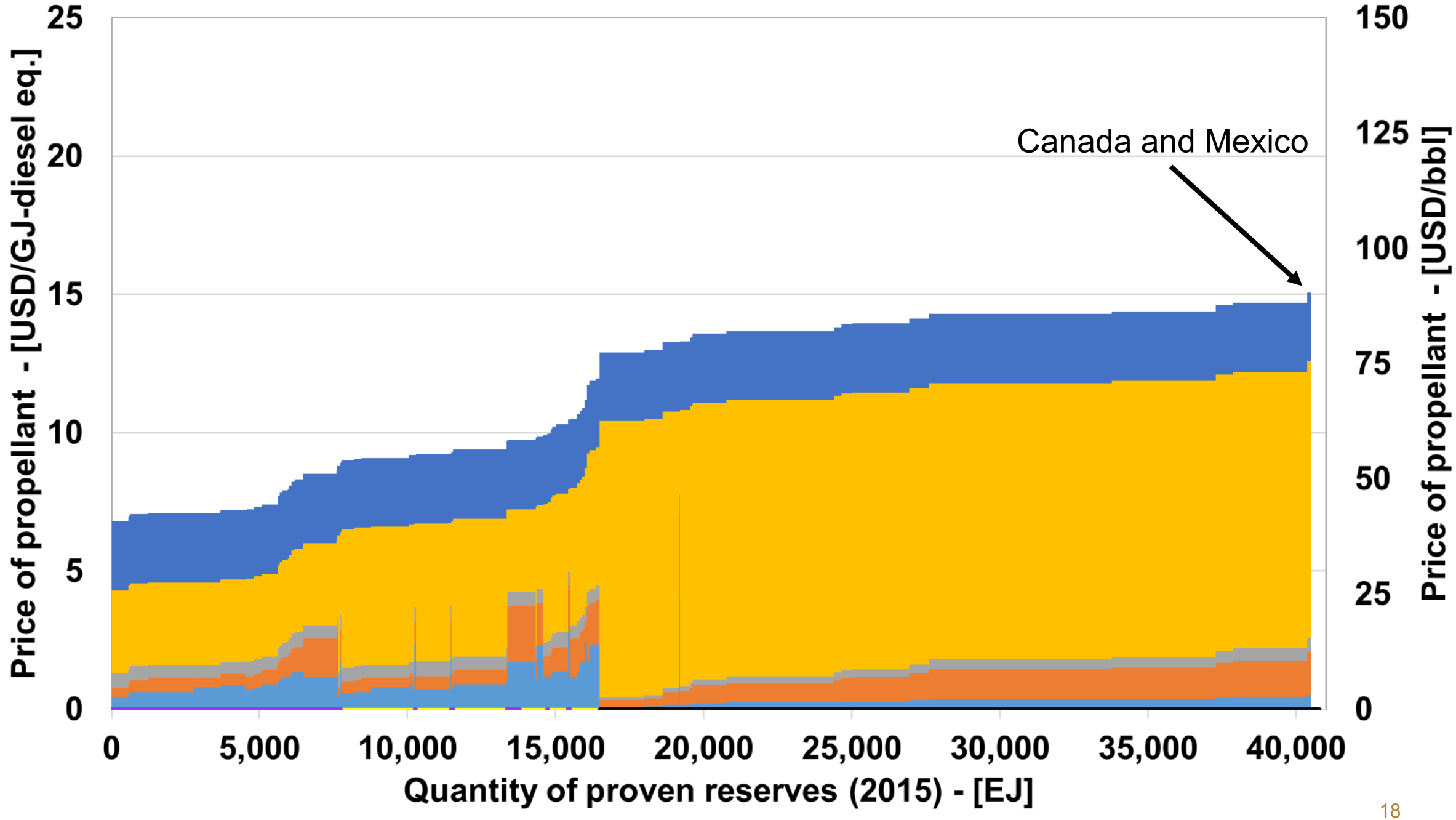
Canada and Mexico
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
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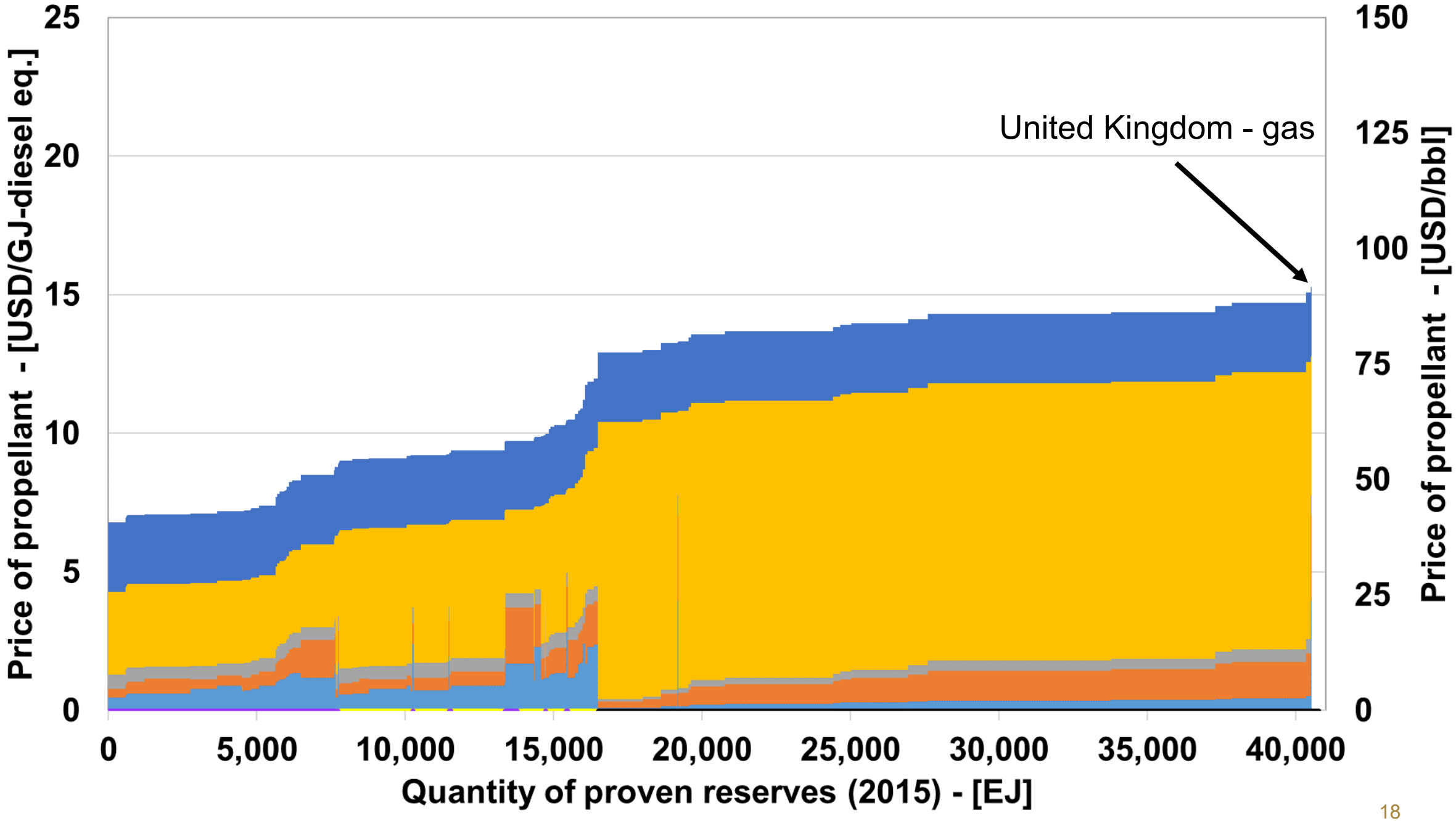
35,000
40,000


United Kingdom - gas
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
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0
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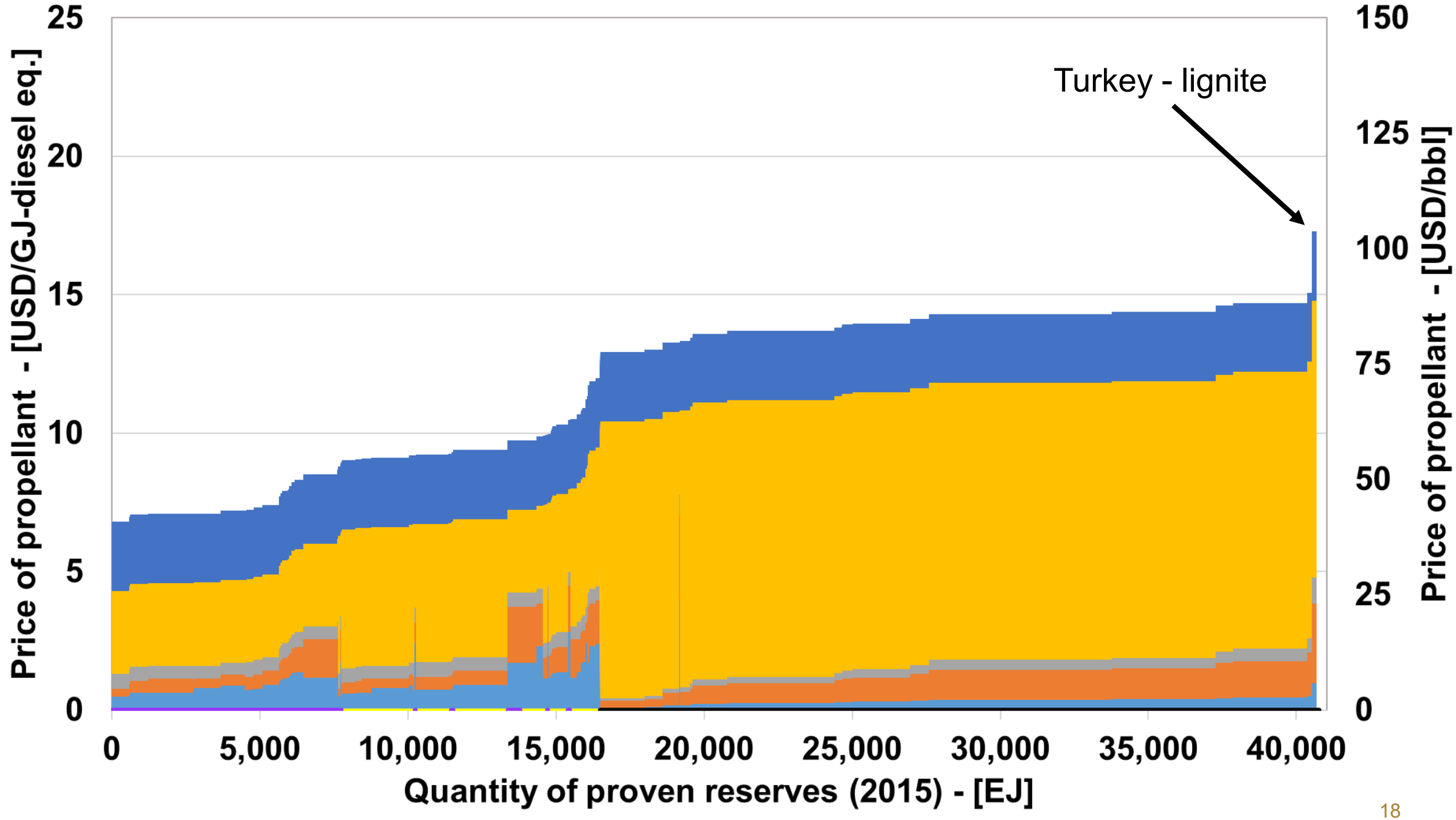
Turkey - lignite
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
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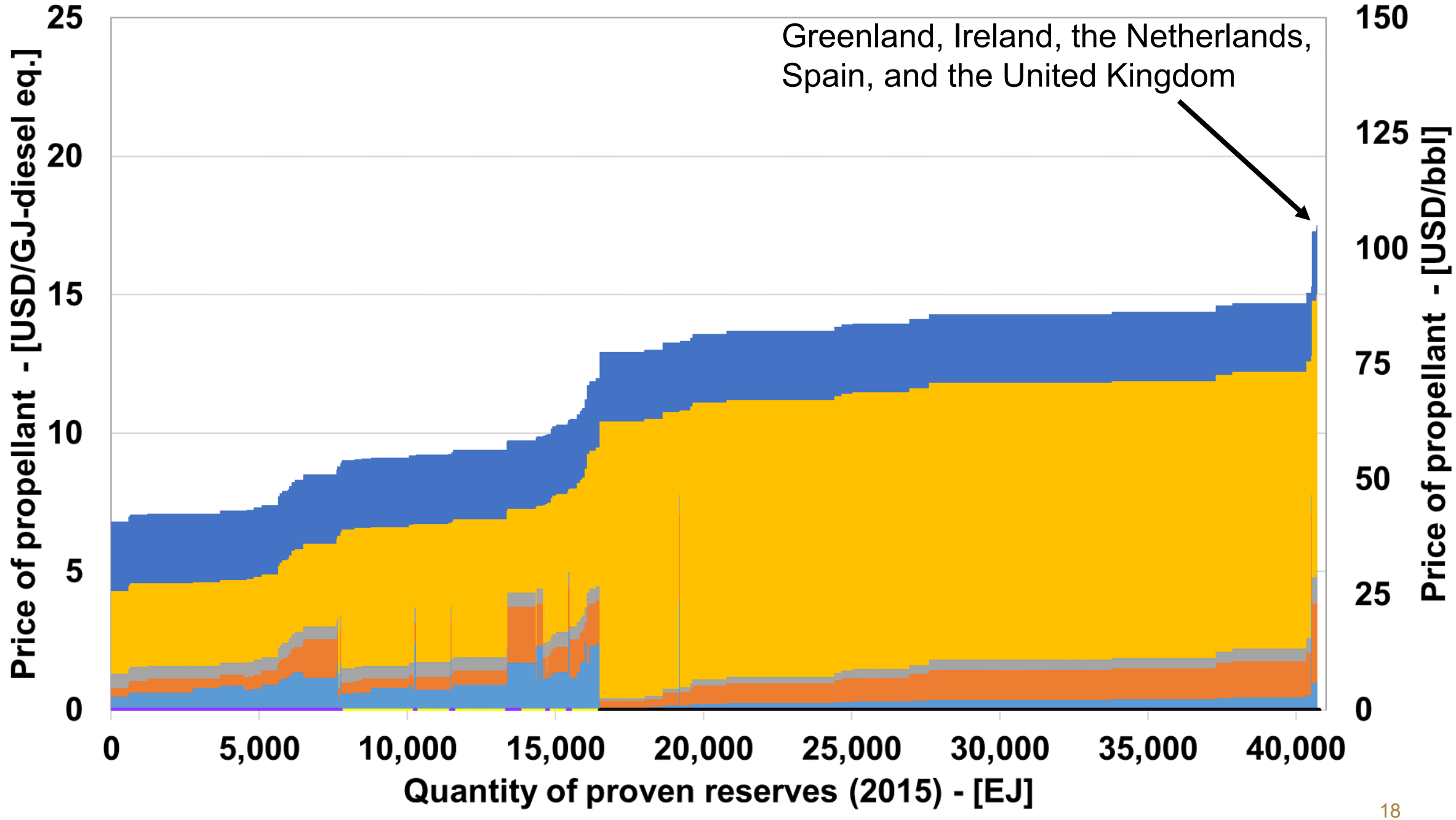
Greenland, Ireland, the Netherlands, Spain, and the United Kingdom
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
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25
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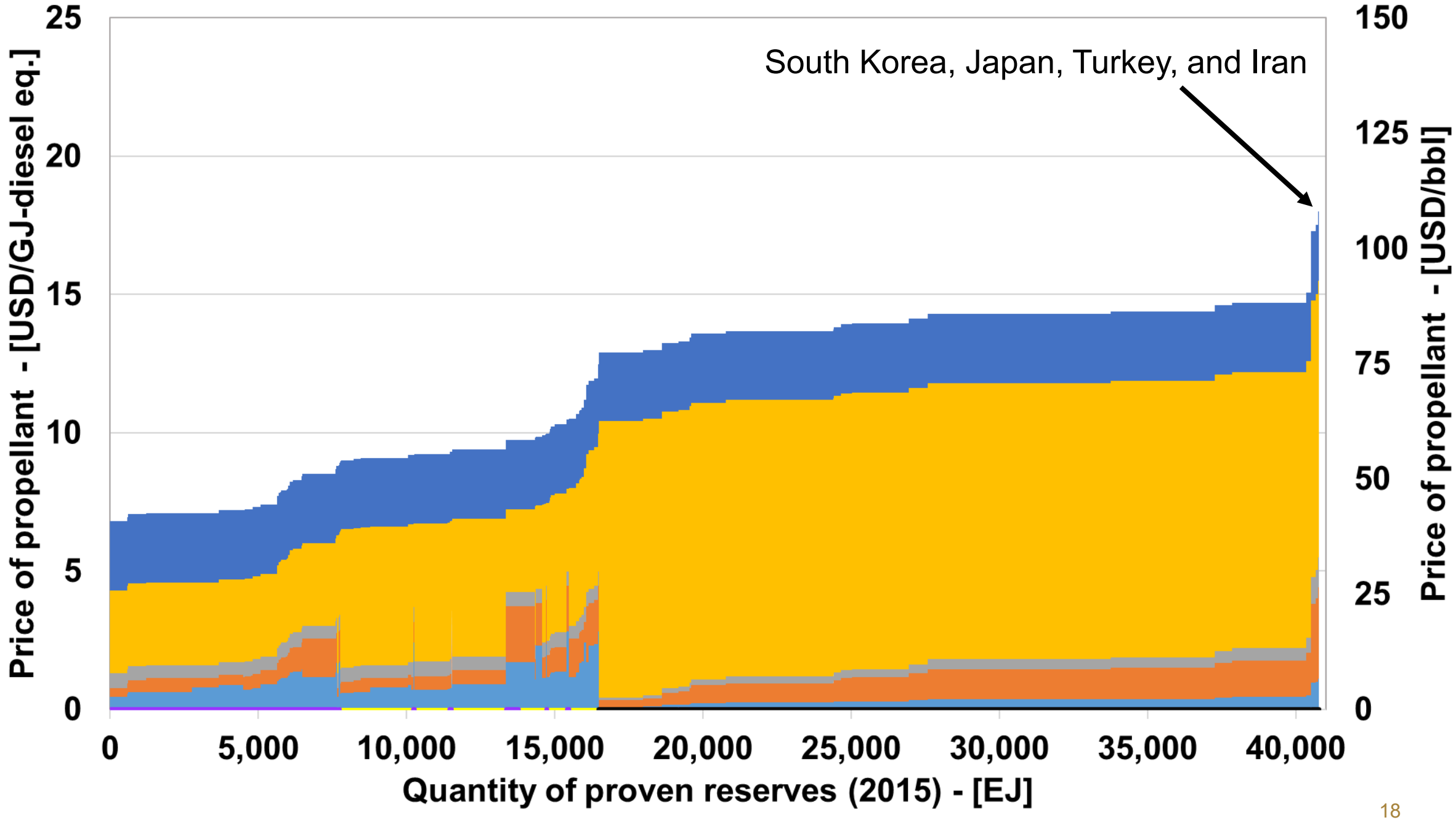
South Korea, Japan, Turkey, and Iran
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
10
15
20
25
0
25
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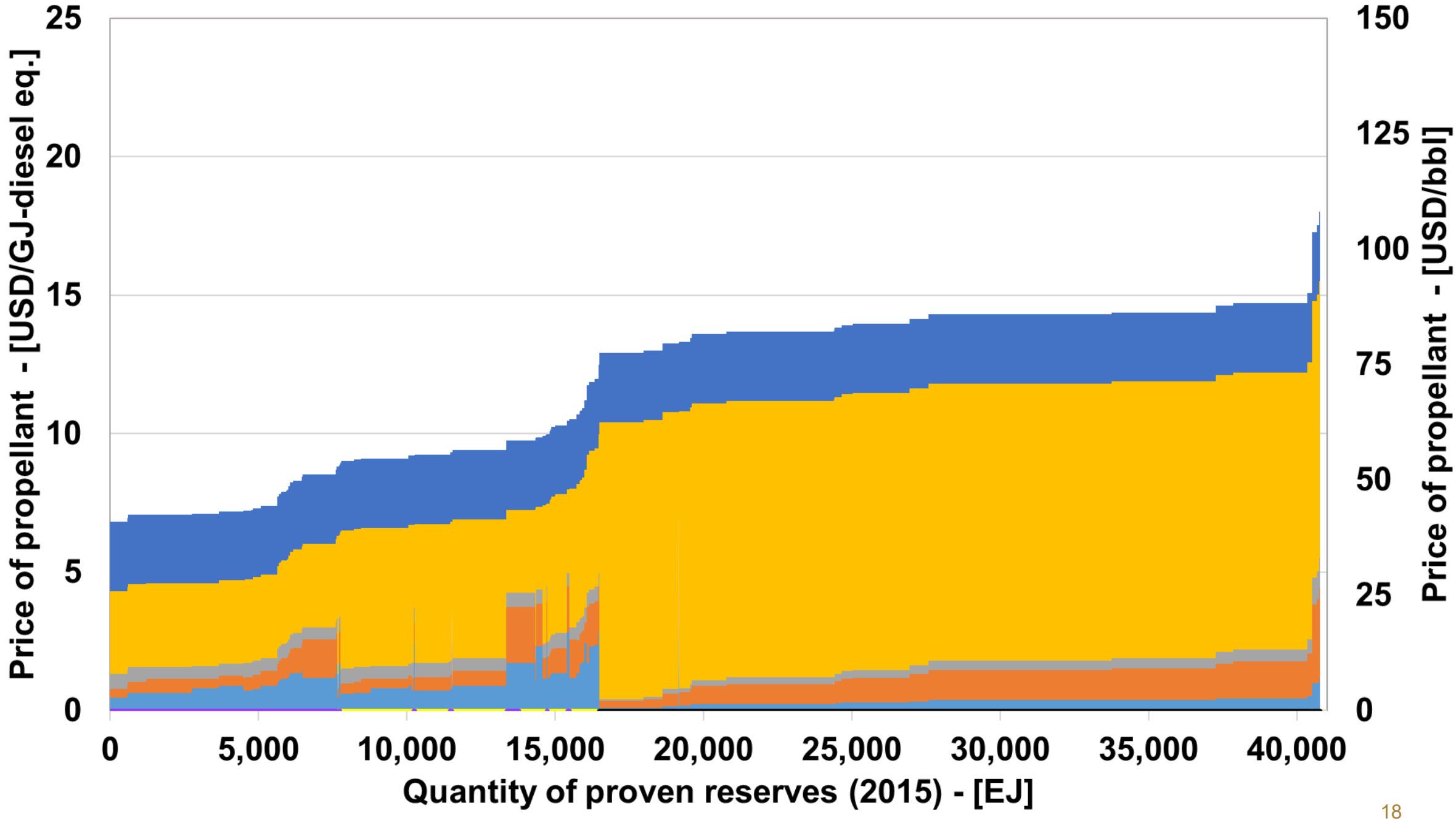
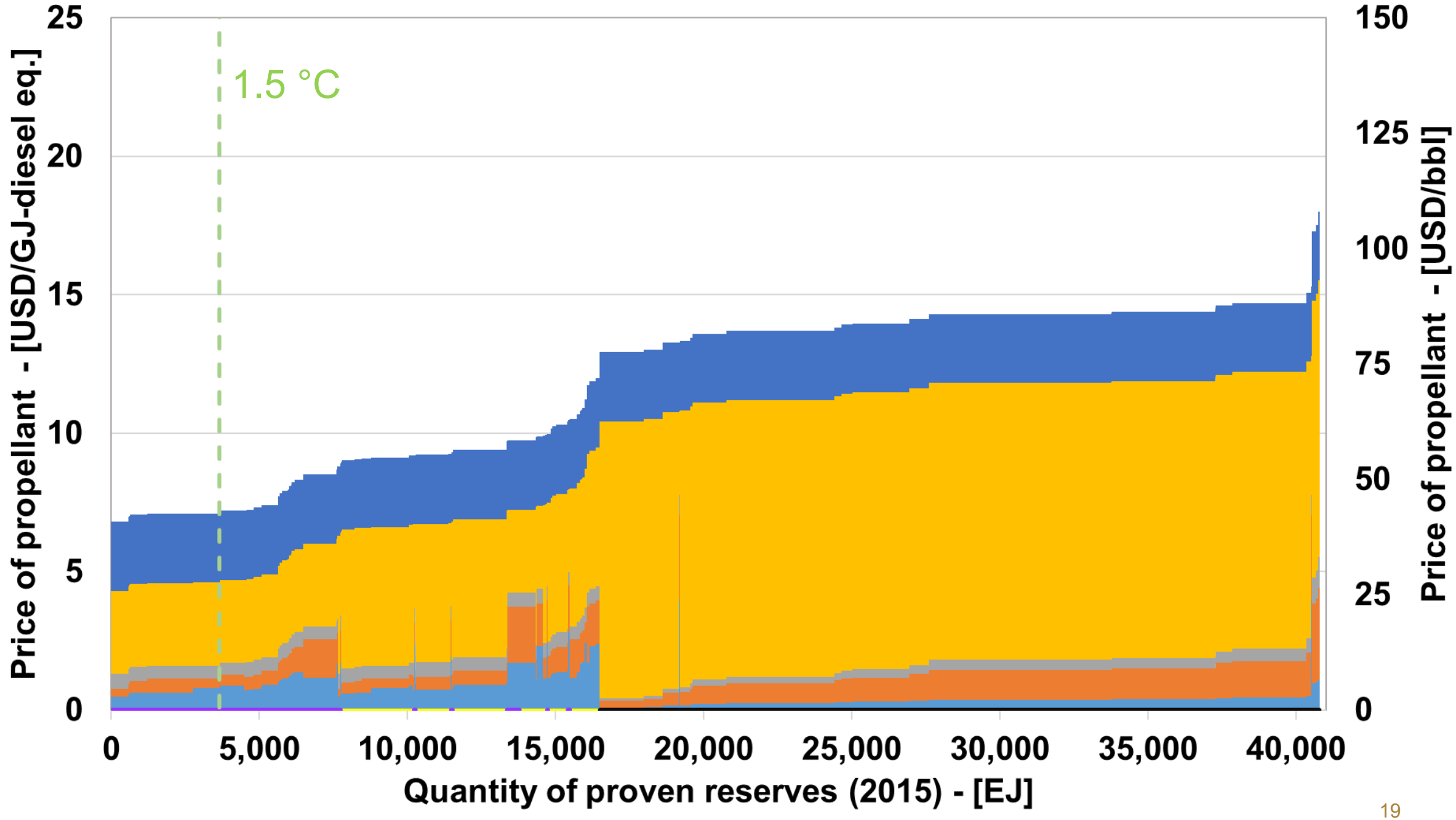

Price of propellant - [USD/GJ-diesel eq.]
25
20
15
10
5
0
Price of propellant - [USD/bbl]
150
125
100
75
50
25
0
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Quantity of proven reserves (2015) - [EJ]


1.5 °C
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
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20
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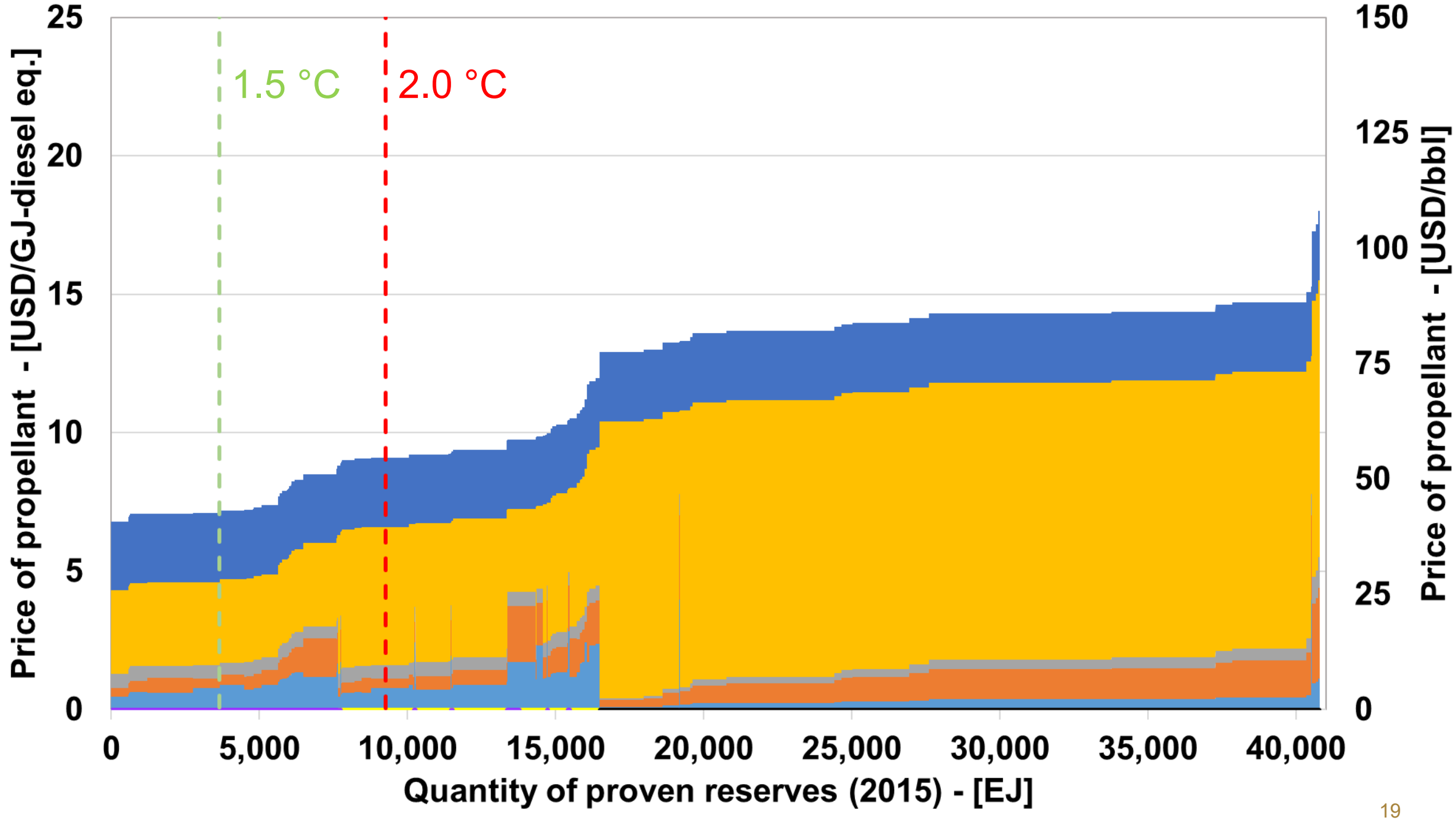
1.5 °C
2.0 °C
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
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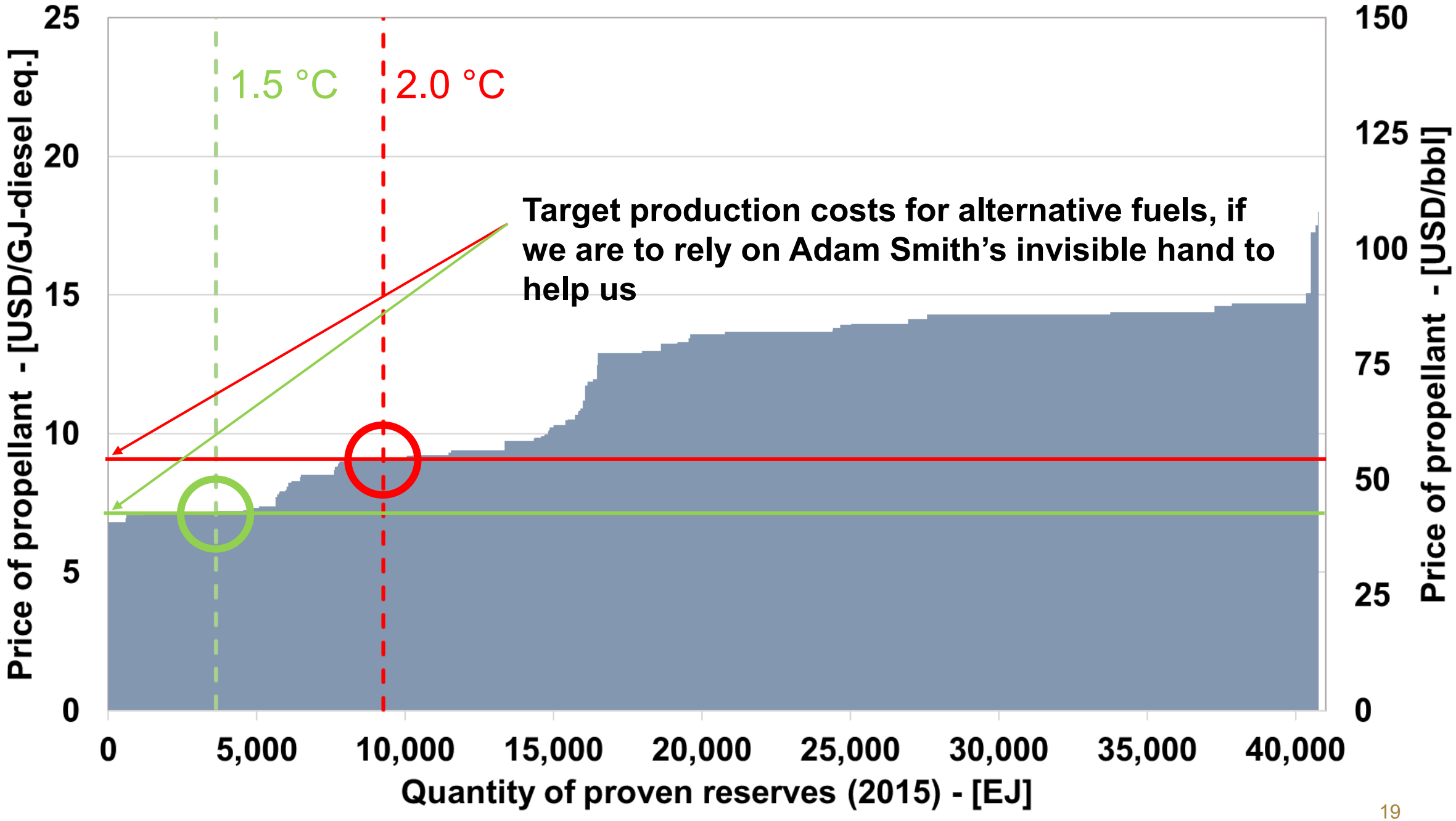
1.5 °C
2.0 °C
Target production costs for alternative fuels, if we are to rely on Adam Smith's invisible hand to help us
Price of propellant - [USD/GJ-diesel eq.]
Price of propellant - [USD/bbl]
Quantity of proven reserves (2015) - [EJ]
0
5
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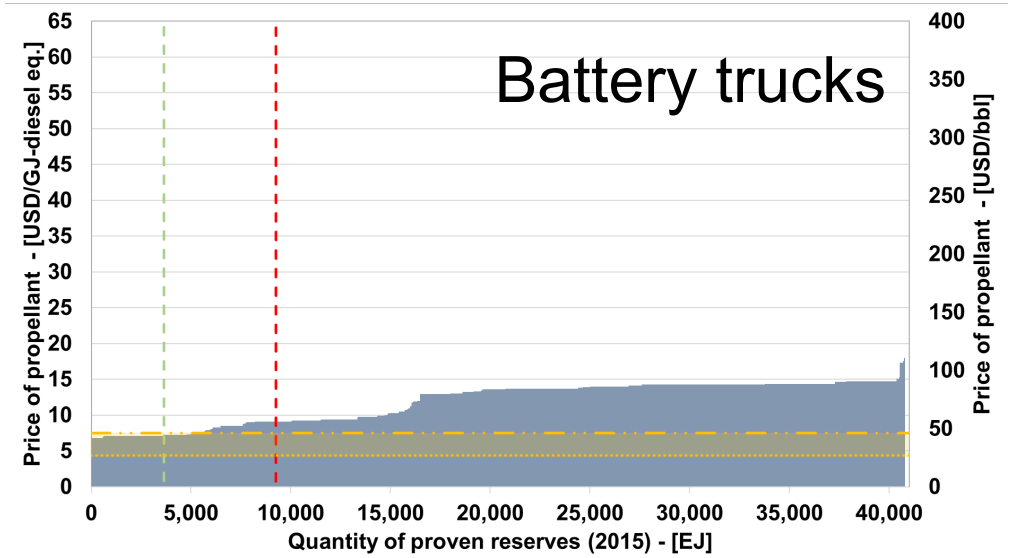
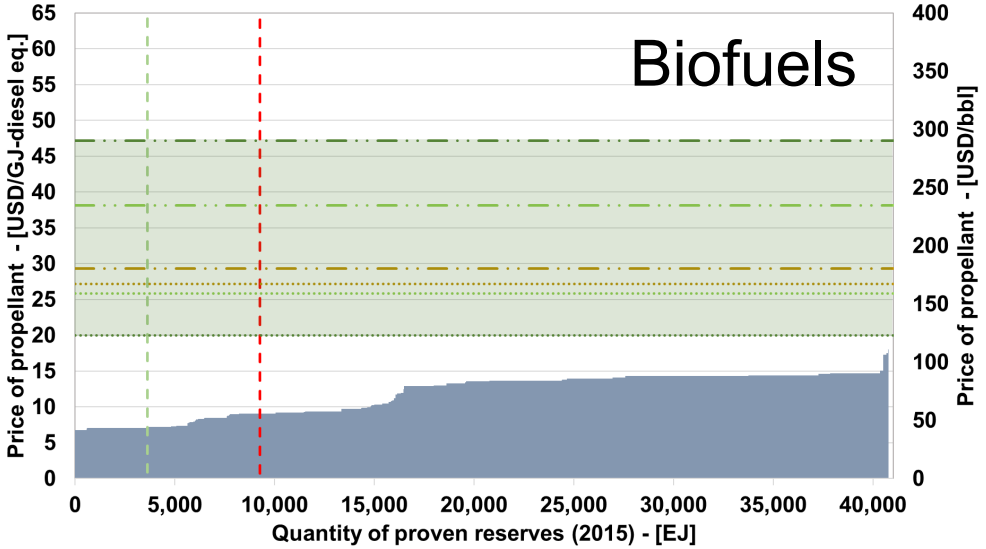
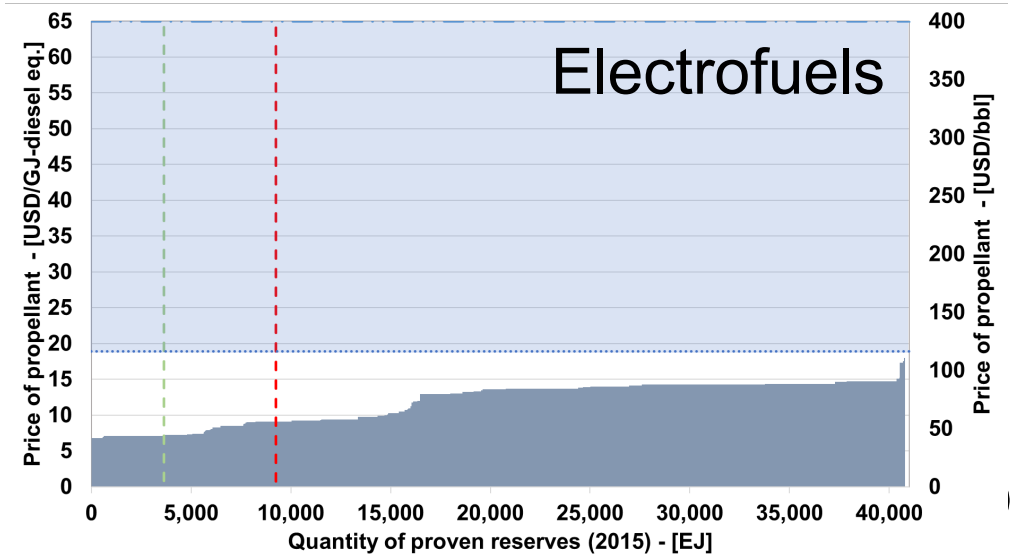
Feasible technical solutions?

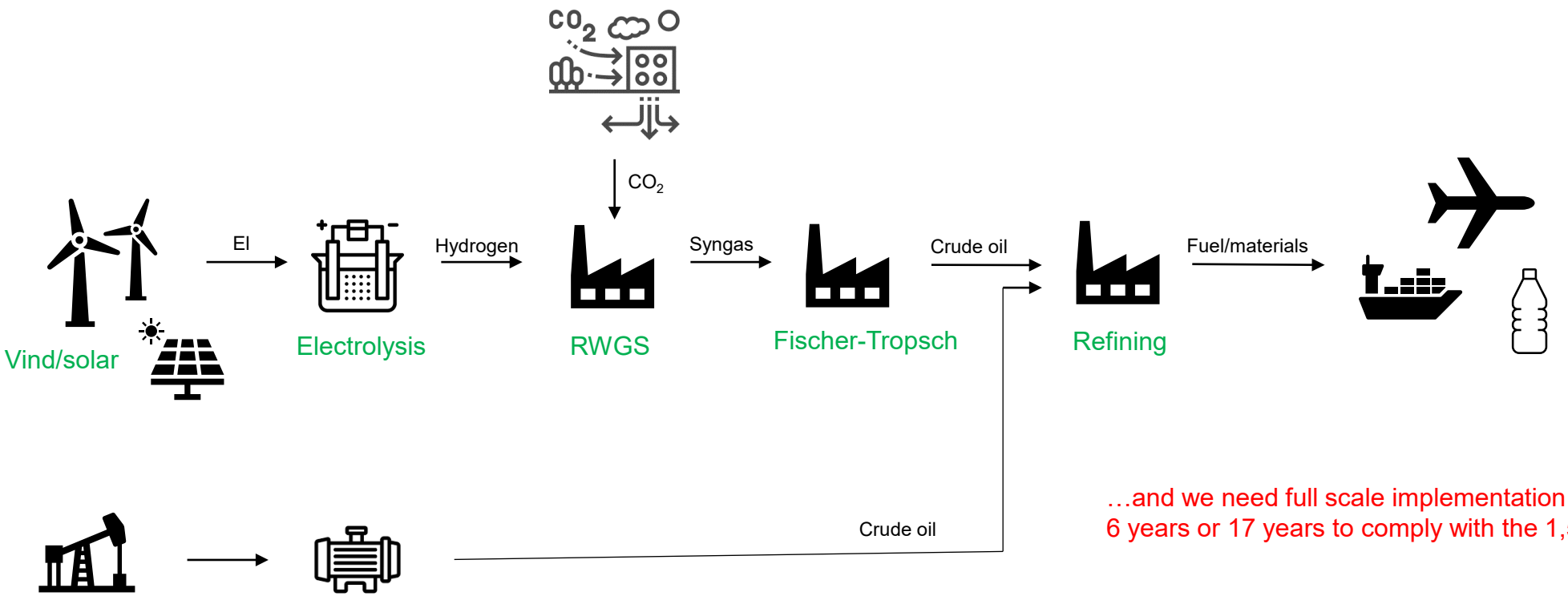






Why do we depend on electrofuels/PtX, and why is it never going to be competitive to fossil fuels?

- One third of our future energy and materials system depend on carbon
- Biofuels not a solution – we would need 5 planets to have sustainable biomass enough. So we need to use CO2 and electrofuels/PtX
- Why will electrofuels never be competitive?



…and we need full scale implementation and substitution of fossil fuels in 6 years or 17 years to comply with the 1,5 and 2 oC targets respectively

SDU