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Residual Mix calculation for three I-REC issuing countries (Brazil, Chile, China)

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This report presents Residual Mix calculations for Brazil, Chile and China for electricity generated in 2021, based on the suggested method and checkpoints procedures as described in the methodology report (Raadal & Mooselu, 2023).

2 Residual Mix calculation for Brazil 2021

2.1 The volume of the Residual Mix for Brazil 2021

This chapter calculates the Residual Mix for Brazil in 2021, based on the suggested method and checkpoints procedures as given in Raadal and Mooselu (2023).

The National Residual Mix for Brazil in 2021 is calculated according to Equation 4 in Raadal and Mooselu (2023):

$$National\ RM_{year\ X} = National\ Generation_{year\ X} - National\ Issued\ attributes\ (vintage\ X)_{January\ year\ X - September\ year\ X+1}$$

The generation volume data for 2021 was taken from https://www.epe.gov.br/en which provides the volume of annually generated electricity, separated into different energy sources such as electricity from bioenergy, solar, wind, hydro, nuclear, oil, gas, coal, and other renewables.

The issued volume was achieved from the dataset by I-REC. Accordingly the dataset was filtered for the vintage year (generation year) 2021, and for Brazil as the issuing country. Based on the above achieved data, the results for the Residual Mix, as well as for total generated electricity and issued I-RECs for Brazil 2021 are presented in Figure 1 and Table 1.

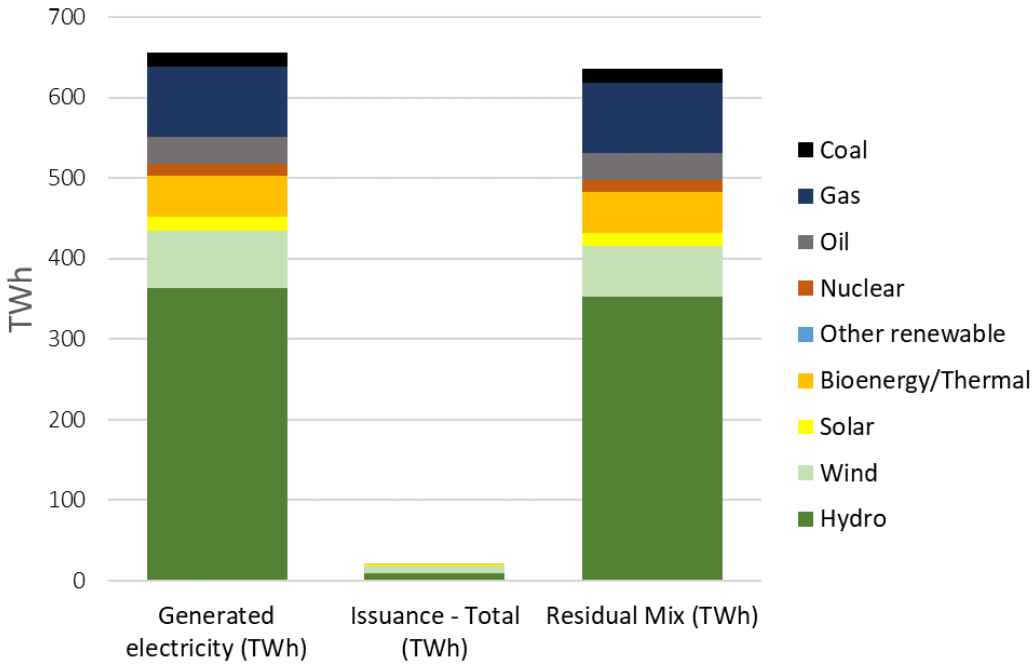

Figure 1 Residual Mix in terms of volume and energy sources for Brazil 2021

Table 1 Different energy sources [TWh] in generated electricity, issued I-RECs and Residual Mix for Brazil 2021

Brazil 2021	Hydro	Wind	Solar	Bioenergy/Thermal	Other renewable	Nuclear	Oil	Gas	Coal	Total	% of generated
Generated electricity (TWh)	362.8	72.3	16.8	51.7	0.0	14.7	33.4	86.9	17.6	656.1	
Issuance I-RECs - Total (TWh	9.9	9.0	0.7	1.3	0.0	0.0	0.0	0.0	0.0	20.8	3.2 %
Residual Mix_I-RECs (TWh)	352.9	63.3	16.1	50.4	0.0	14.7	33.4	86.9	17.6	635.3	96.8 %

As seen in Figure 1 and Table 1, the issued and Residual Mix volumes represent 3.2% and 96.8% of the total generated volume, respectively. The issued volume also represents 4.1% of generated renewable electricity.

As no other tracking mechanisms have been provided for Brazil, the calculations only take I-RECs into account.

2.2 Additional assumption tests for Brazil 2021

Chapters 2.2.1 and 2.2.2 describe the recommended procedures for verifying the potential impact of the assumptions for the modified calculation method.

2.2.1 Checkpoint 1, Brazil vintage year 2021: The volume of unredeemed I-RECs

As described in chapter 4in Raadal and Mooselu (2023), the Residual Mixes are suggested to be published maximum one year after end of generation year (2021). According to Equation 5 in Raadal and Mooselu (2023), the volume of issued, but unredeemed I-RECs (vintage X) in country A by end of year X+1 is expressed as follows:

$$Issued\ unredeemed\ I\text{-}RECs_X = National\ Issued\ Volume_{X+1} - R_{Na,\ X+1} - R_{E,\ X+1}$$

When applying this equation for Brazil for vintage year 2021 it turns out as follows:

$$Issued\ unredeemed\ I\text{-}RECs_{2021} = National\ Issued\ Volume_{2022} - R_{Na,\ 2022} - R_{E,\ 2022}$$

Where:

National Issued Volume $_{2022}$ =	Total issued I-RECs for electricity generated in Brazil in 2021 by end of 2022 (MWh)
$R_{Na,\ 2022}$: Redeemed National$_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by end of year 2022, issued and redeemed in Brazil (MWh)
$R_{E,\ 2022}$: Redeemed exported$_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by end of 2022, issued in Brazil and redeemed in another country (MWh)

Based on data provided by I-REC and the and the equation above, the calculated volume of unredeemed I-RECs generated in Brazil in 2021 is 2.864 TWh per the 31st of December 2022 (see calculation and Figure 2 below).

$$Issued\ unredeemed\ I\text{-}RECs_{2021} = 20.829\ TWh - 17.255\ TWh - 0.709\ TWh = 2.864\ TWh$$

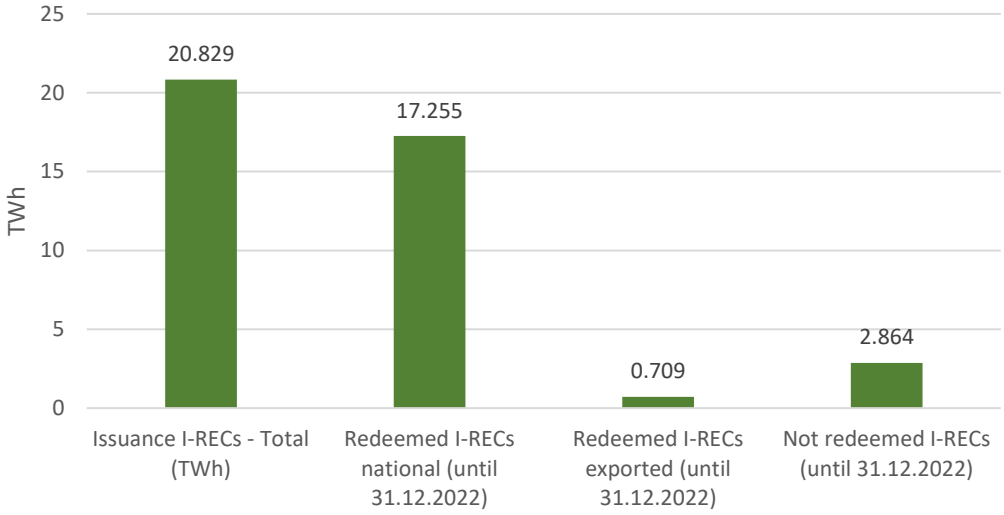

Figure 2 Unredeemed I-RECs (vintage 2021 Brazil) by end of 2022.

The gap between issued and unredeemed I-RECs (2.86 TWh) represents 13.8% of the total issued volume as well as 0.43% and 0.45% of the respective total generated electricity and Residual Mix volume in Brazil 2021. Since the Residual Mix calculation withdraws all the issued I-RECs, it contains less renewable electricity attributes than what is the actual situation at the date of publication. However, as the gap only represents 0.45% of the Residual Mix volume, the impact on the Residual Mix can be assessed negligible. Hence, the simplification of assuming all I-RECs to be redeemed is reasonable.

It should be emphasised that the issued I-RECs still can be redeemed after the date of publication, which means that the Residual Mix will most likely move towards the one being calculated.

2.2.2 Checkpoint 2, Brazil vintage year 2021: Surplus/deficit of attributes

Based on Equation 6 in Raadal and Mooselu (2023), the untracked volume for Brazil in 2021 is calculated as follows:

$$\textit{Untracked Electricity Consumption}_X = \textit{National Generation Volume}_X - R_{Na,\,X+1} - R_{I,\,X+1}$$

When applying this equation for Brazil for vintage year 2021 it turns out as follows:

$$\textit{Untracked Electricity Consumption}_{2021} = \textit{National Generation Volume}_{2021} - R_{Na,\,2022} - R_{I,2022}$$

Where:

National Generation Volume$_{2021}$ =	Generated electricity in 2021 in Brazil (MWh)
$R_{Na,\,2022}$: Redeemed National $_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of 20221, issued and redeemed in Brazil (MWh)
$R_{I,\,2022}$: Redeemed imported $_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of year 2022, issued in another country and redeemed in Brazil (MWh)

Based on data provided by I-REC and the equation above, the Untracked Electricity Consumption in Brazil 2021 (per December 31st, 2022), is calculated to 638.853 TWh (see calculation and Figure 3 below).

$$\textit{Untracked Consumption}_{2021} = 656.109\ TWh - 17.255\ TWh - 0.0004\ TWh = 638.853\ TWh$$

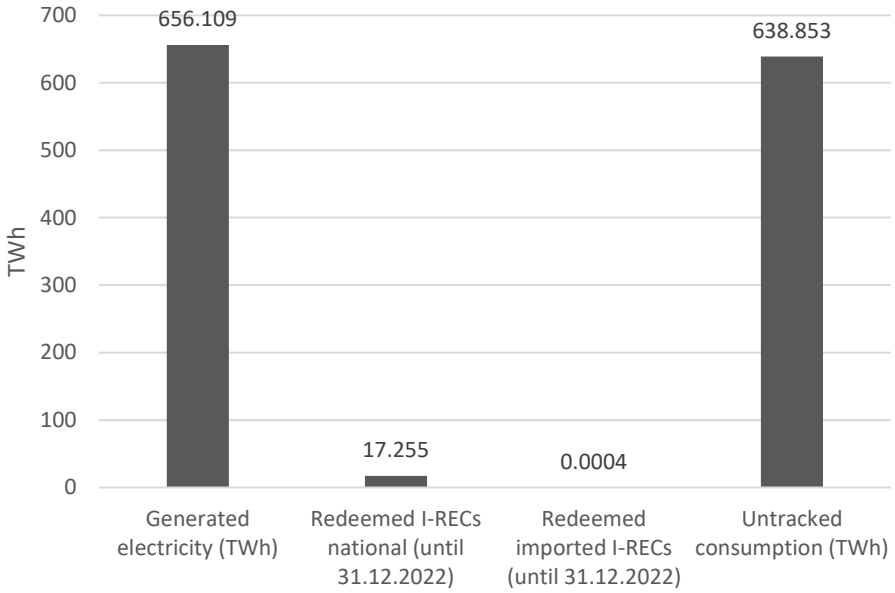

Figure 3 Untracked consumption 2021 in Brazil by end of 2022.

According to Equation 7 in Raadal and Mooselu (2023), the deficit of attributes for Untracked consumption in Brazil (vintage 2021) is calculated to 3.573 TWh (see calculation and Figure 4 below).

Surplus/deficit of attributes = National Residual Mix$_{yearX}$ - Untracked Consumption$_{yearX}$

When applying this equation for Brazil for vintage year 2021 it turns out as follows:

Surplus/deficit of attributes = 635.280 TWh – 638.853 TWh = - 3.573 TWh

The same value applies when using Equation 8 in Raadal and Mooselu (2023) for calculating the surplus/deficit of attributes:

Surplus/Deficit = $R_{I, X+1}$ - $R_{E, X+1}$ – I_{NR} = 0.0004 TWh – 0.709 TWh – 2.864 TWh = -3.573 TWh

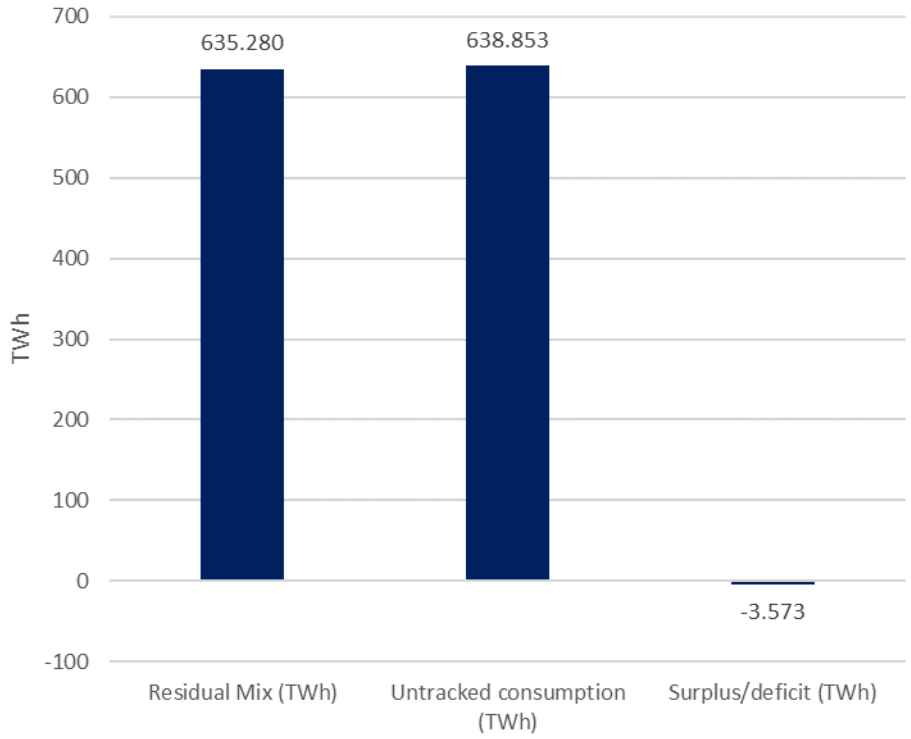

Figure 4 Deficit of attributes (vintage 2021 Brazil) based on Residual Mix and Untracked consumption by end of 2022.

Figure 4 shows that there is a deficit of attributes for the untracked consumption of 3.573 TWh. This volume represents 0.6% of the untracked consumption in Brazil in 2021. The deficit is mainly caused by the unredeemed I-RECs (I_{NR} = 2.864 TWh, as seen above), which are withdrawn in the Residual Mix but not in the Untracked consumption. As long as the attribute deficit is this low compared to the untracked consumption, the simplification of applying the Residual Mix attributes to the Untracked consumption seems reasonable.

2.3 Direct CO_2 emission factor for the Brazilian Residual Mix 2021

The direct CO_2 emission factor for the national Residual Mix can be calculated in two different ways dependent on the availability of data, as given by Equations 9 and 10 in Raadal and Mooselu (2023).

1. Based on the national emission factor (EF_{Na})

EF_{RM} = EF_{Na} * Volume Total generation [TWh]/Volume Residual Mix [TWh]
= 0.1264 Mt CO_2/TWh * 656.1 TWh/635.3 TWh = 0.131 Mt CO_2/TWh = 0.131 kg CO_2/kWh

2. Based on specific emission factors for each energy source in the Residual Mix

$$EF_{RM} = \frac{\sum_{k=1}^{n} kg\ CO2\ per\ kWh_{energy\ source\ k} * kWh_{energy\ source\ k}}{\text{Volume Residual Mix [kWh]}}$$

where k is the number of energy sources in the Residual Mix.

Based on the above equation and emission factors per energy source from Annex 3 in AIB (Association of Issuing Bodies) (2023), the direct CO_2 emission factor for the Brazilian Residual Mix 2021 is calculated. This is presented in Table 2.

Table 2 Direct emission factor [kg CO_2/kWh] for the Brazilian Residual Mix 2021.

Brazilian Residual Mix 2021	Hydro	Wind	Solar	Bioenergy/ Thermal	Other renewable	Nuclear	Oil	Gas	Coal	Total
Residual Mix [TWh]	352.934	63.3219	16.0967	50.385532	0	14.705	33.391	86.861	17.585	635.28
Emission factor per energy source [kg CO2/kWh]	0	0	0	0	0	0	0.77	0.44	0.86	
Total emissions [Mtonn CO2]	0	0	0	0	0	0	25.61	37.87	15.16	78.64
Emission factor Residual Mix [kg CO2/kWh]										0.124

As seen in Table 2, the direct emission factor for the Brazilian Residual Mix 2021 is 0.124 kg CO_2/kWh, hence some lower than the calculated emission factor based on approach 1 above.

3 Residual Mix calculation for Chile 2021

3.1 The volume of the Residual Mix for Chile 2021

This chapter calculates the Residual Mix for Chile in 2021, based on the suggested method and checkpoints procedures as given in Raadal and Mooselu (2023).

The National Residual Mix for Chile in 2021 is calculated according to Equation 4 in Raadal and Mooselu (2023):

$$National\ RM_{year\ X} = National\ Generation_{year\ X} - National\ Issued\ attributes\ (vintage\ X)_{January\ year\ X - September\ year\ X+1}$$

The electricity generation data for 2021 was taken from national sources provided by I-REC. The generation data is separated into different energy sources such as electricity from bioenergy, solar, wind, hydro, nuclear, oil, gas, coal, and other renewables.

The issued volume was achieved from the dataset given by I-REC. Accordingly the dataset was filtered for the vintage year (generation year) 2021, and for Chile as the issuing country. Based on the above achieved data, the results for the Residual Mix, as well as for total generated electricity and issued I-RECs for Chile 2021 are presented in Figure 5 and Table 3.

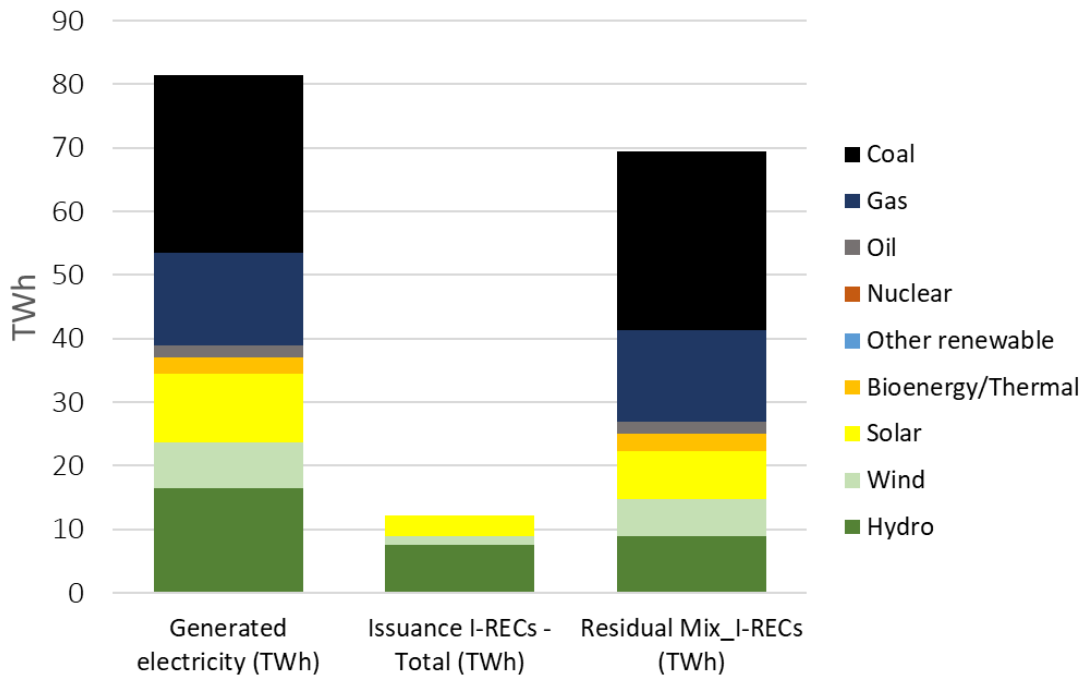

Figure 5 Residual Mix in terms of volume and energy sources for Chile 2021.

Table 3 Different energy sources [TWh] in generated electricity, issued I-RECs and Residual Mix for Chile 2021.

	Hydro	Wind	Solar	Bioenergy/Thermal	Other renewable	Nuclear	Oil	Gas	Coal	Total	% of generated
Generated electricity (TWh)	16.5	7.2	10.8	2.7	0.0	0.0	1.9	14.5	28.0	81.5	
Issuance I-RECs - Total (TWh)	7.6	1.3	3.2	0.0	0.0	0.0	0.0	0.0	0.0	12.1	14.9 %
Residual Mix_I-RECs (TWh)	8.9	5.9	7.6	2.7	0.0	0.0	1.9	14.5	28.0	69.4	85.1 %

As seen in Figure 5 and Table 3, the Issued and Residual Mix volumes represent 14.9% and 85.1% of the total generated volume, respectively. The issued volume also represents 34.8% of generated renewable electricity.

In Chile, there is an additional tracking instrument (RENOVA) beyond I-REC, which represented an issued volume of 8 TWh in 2021. As detailed data for distribution of the issued volume into different energy sources is not available, this volume is excluded from Figure 5 and Table 3. When adding this issued volume to the issued I-REC volume, the total issued volume becomes 20.1 TWh. Hence, the issued and Residual Mix volumes represent 24.7% and 75.3% of the total generated volume, respectively.

3.2 Additional assumption tests for Chile 2021

Chapters 3.2.1 and 3.2.2 describe the recommended procedures for verifying the potential impact of the assumptions for the modified calculation method.

It should be noted that the assessments of checkpoints 1 and 2 are based on I-RECs data only, not including data from the other tracking mechanism (RENOVA). The reason for this is lack of data for the issued volume separated into different energy sources and lack of redemption data from this.

3.2.1 Checkpoint 1, Chile vintage year 2021: The volume of unredeemed I-RECs

As described in chapter 4 in Raadal and Mooselu (2023), the Residual Mixes are suggested to be published maximum 1 year after end of generation year (2021). According to Equation 5 in Raadal and Mooselu (2023), the volume of issued but unredeemed I-RECs (vintage X) in country A by end of year X+1 is expressed as follows:

$$Issued\ unredeemed\ I\text{-}RECs_X = National\ Issued\ Volume_{X+1} - R_{Na,\ X+1} - R_{E,\ X+1}$$

When applying this equation for Chile for vintage year 2021 it turns out as follows:

$$Issued\ unredeemed\ I\text{-}RECs_{2021} = National\ Issued\ Volume_{2022} - R_{Na,\ 2022} - R_{E,\ 2022}$$

Where:

National Issued Volume $_{2022}$ =	Total issued I-RECs for electricity generated in Chile in 2021 by the end of 2022 (MWh)
$R_{Na,\ 2022}$: Redeemed National$_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of year 2022, issued and redeemed in Chile (MWh)
$R_{E,\ 2022}$: Redeemed exported$_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of 2022, issued in Chile and redeemed in another country (MWh)

Based on data provided by I-REC and the equation above, the calculated volume of unredeemed I-RECs generated in Chile in 2021 is 3.873 TWh per the 31st of December 2022 (see calculation and Figure 6 below).

$$Issued\ unredeemed\ I\text{-}RECs_{2021} = 12.123\ TWh - 8.208\ TWh - 0.042\ TWh = 3.873\ TWh$$

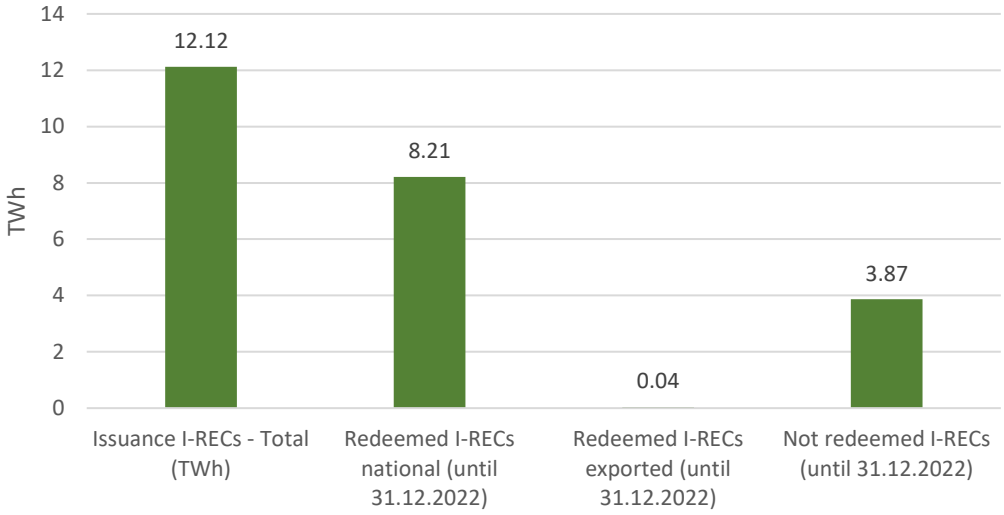

Figure 6 Unredeemed I-RECs (vintage 2021 Chile) by end of 2022.

The gap between issued and unredeemed I-RECs (3.873 TWh) represents 32 % of total issued volume, as well as 4.8% and 5.6% of the respective total generated electricity and Residual Mix volume in Chile in 2021. Hence, 4.8% of the total generated renewable electricity volume is considered when calculating the Residual Mix despite being redeemed. The Residual Mix calculation withdraws all the issued I-RECs, and therefore contains less renewable electricity attributes than what is the actual situation at the date of publication. The gap still represents a limited share (5.6 %) of the Residual Mix volume which means that the impact on the Residual Mix emission factor can still be assumed small.

However, if the gap becomes significantly large, the I-REC standard should consider implementing an expiry date for I-RECs (like in the European GO system).

3.2.2 Checkpoint 2, Chile vintage year 2021: Surplus/deficit of attributes

Based on Equation 6 in Raadal and Mooselu (2023), the untracked volume for Chile in 2021 is calculated as follows:

$$\textit{Untracked Electricity Consumption}_X = \textit{National Generation Volume}_X - R_{Na,\,X+1} - R_{I,\,X+1}$$

When applying this equation for Chile for vintage year 2021 it turns out as follows:

$$\textit{Untracked Electricity Consumption}_{2021} = \textit{National Generation Volume}_{2021} - R_{Na,\,2022} - R_{I,2022}$$

Where:

National Generation Volume$_{2021}$ =	Generated electricity in 2021 in Chile (MWh)
$R_{Na,\,2022}$: Redeemed National $_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of 20221, issued and redeemed in Chile (MWh)
$R_{I,\,2022}$: Redeemed imported $_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of year 2022, issued in another country and redeemed in Chile (MWh)

Based on data provided by I-REC and the equation above, the Untracked Electricity Consumption in Chile 2021 (per December 31st, 2022), is calculated to 73.288 TWh (see calculation and Figure 7 below). Again, it

should be noted that only I-RECs are included in the calculations as there are no official redemption data for the other tracking mechanism.

Untracked Consumption$_{2021}$ = 81.49 TWh – 8.21 TWh – 0.02 TWh = 73.27 TWh.

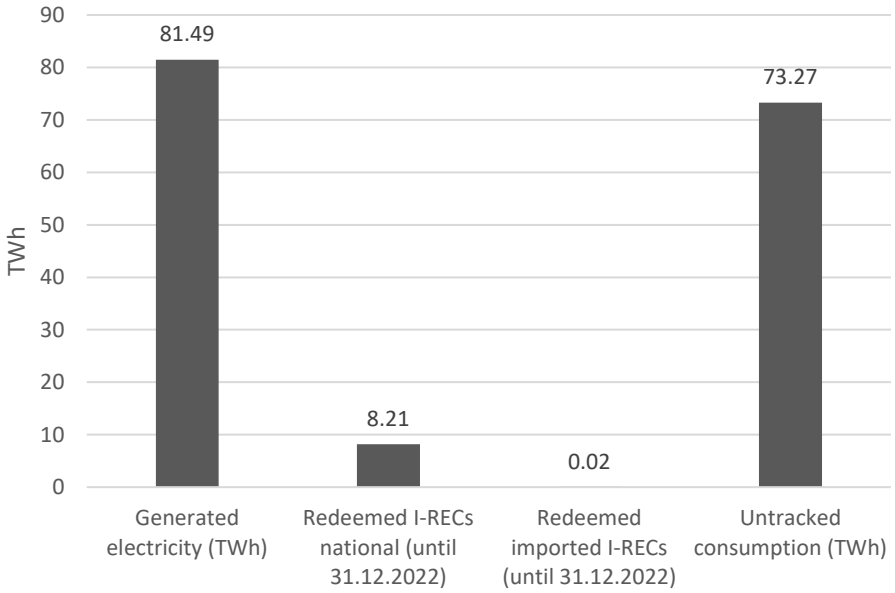

Figure 7 Untracked consumption 2021 in Chile by end of 2022.

According to Equation 7 in Raadal and Mooselu (2023), the deficit of attributes for Untracked consumption in Chile (vintage 2021) is calculated to 3,899 MWh (see calculation and Figure 8 below).

Surplus/deficit of attributes = National Residual Mix$_{yearX}$ - Untracked Consumption$_{yearX}$

Surplus/deficit of attributes = 69.370 TWh – 73.269 TWh = - 3.899 TWh

The same value applies when using Equation 8 in Raadal and Mooselu (2023) for calculating the surplus/deficit of attributes:

Surplus/Deficit = $R_{I, X+1}$ - $R_{E, X+1}$ – I_{NR} = 0.016 TWh – 0.042 TWh – 3.873 TWh = -3.899 TWh

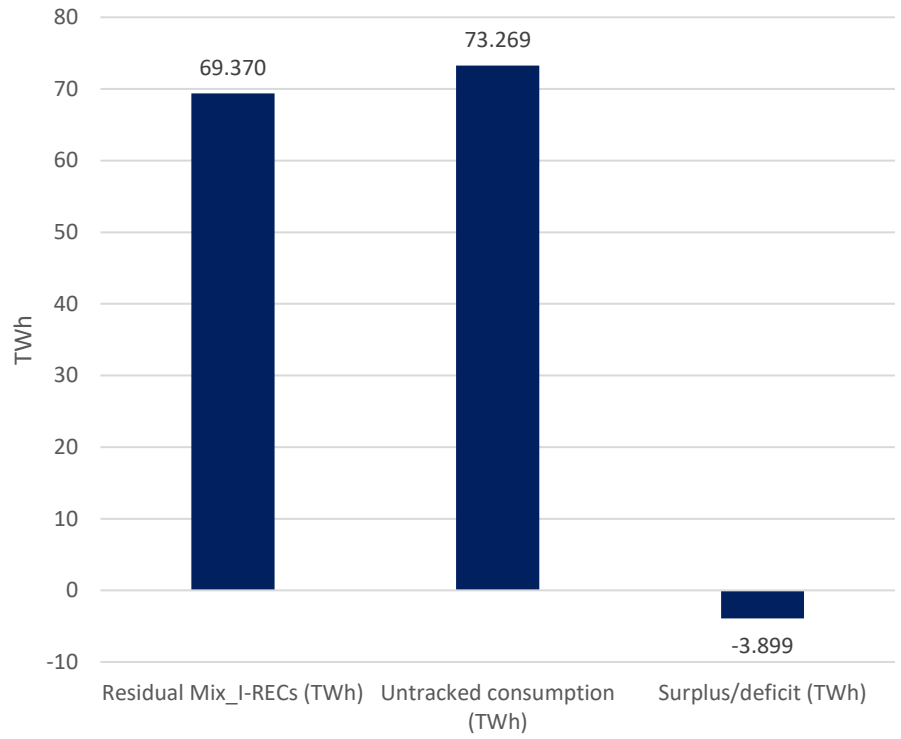

Figure 8 Deficit of attributes (vintage 2021 Chile) based on Residual Mix and Untracked consumption by end of 2022.

Figure 8 shows that there is a deficit of attributes for the untracked consumption of 3.9 TWh. This volume represents 5.3% of the untracked consumption in Chile in 2021. The deficit is mainly caused by the unredeemed I-RECs (I_{NR} = 3.873 TWh, as seen above), which are withdrawn in the Residual Mix but not in the Untracked consumption. However, as long as the attribute deficit still is relatively low compared to the untracked consumption, the simplification of the methodology seems reliable.

3.3 Direct CO_2 emission factor for the Chilean Residual Mix 2021

The calculated emission factor for the national Residual Mix is calculated for the issued volume which includes both I-RECs and the other tracking instrument (RENOVA), in total 20.1 TWh, which means a Residual Mix volume of 61.35 TWh.

As presented for Brazil in chapter chapters 2.3, the direct CO_2 emission factor for the national Residual Mix can be calculated in two different ways dependent on the availability of data, as given by Equations 9 and 10 in Raadal and Mooselu (2023).

1. Based on the national emission factor (EF_{Na})

$EF_{RM} = EF_{Na}$ * Volume Total generation [TWh]/Volume Residual Mix [TWh]
= 0.391 Mt CO_2/TWh * 81.49 TWh/61.35 TWh = 0.520 Mt CO_2/TWh = 0.520 kg CO_2/kWh

2. Based on specific emission factors for each energy source in the Residual Mix

$$EF_{RM} = \frac{\sum_{k=1}^{n} kg\ CO2\ per\ kWh_{energy\ source\ k} * kWh_{energy\ source\ k}}{\text{Volume Residual Mix [kWh]}}$$

where k is the number of energy sources in the Residual Mix.

Based on the above equation and emission factors per energy source from Annex 3 in AIB (Association of Issuing Bodies) (2023), the direct CO_2 emission factor for the Chilean Residual Mix 2021 is calculated. This is presented in Table 4.

Table 4 Direct emission factor [kg CO_2/kWh] for the Chilean Residual Mix 2021.

Chilean Residual Mix 2021	Hydro	Wind	Solar	Bioenergy/ Thermal	Other renewable	Nuclear	Oil	Gas	Coal	Total
Residual Mix [TWh]*	8.86	5.90	7.59	2.65	0.00	0.00	1.86	14.49	28.02	61.35
Emission factor per energy source [kg CO2/kWh]	0	0	0	0	0	0	0.77	0.44	0.86	
Total emissions [Mtonn CO2]	0	0	0	0	0	0	1.42	6.32	24.16	31.90
Emission factor Residual Mix [kg CO2/kWh]										0.520

* The total volume includes 8 TWh from the other tracking instrument.

As seen in Table 4, the direct emission factor for the Chilean Residual Mix 2021 is 0.520 kg CO_2/kWh, which equals the calculated emission factor based on approach 1 above.

4 Residual Mix calculation for China 2021

4.1 The volume of the Residual Mix for China 2021

This chapter calculates the Residual Mix for China in 2021, based on the suggested method and checkpoints procedures as given in Raadal and Mooselu (2023).

The National Residual Mix for Chile in 2021 is calculated according to Equation 4 in Raadal and Mooselu (2023):

$$National\ RM_{year\ X} = National\ Generation_{year\ X} - National\ Issued\ attributes\ (vintage\ X)_{1.1\ year\ X\ -\ 30.9\ year\ X+1}$$

The generation volume data for 2021 was taken from https://ourworldindata.org/energy, which provides the total volume of annually generated electricity, separated into different energy sources such as electricity from bioenergy, solar, wind, hydro, nuclear, oil, gas, coal, and other renewables.

The issued volume was achieved from the dataset by I-REC. Accordingly the dataset was filtered for the vintage year (generation year) 2021, and for China as the issuing country. Based on the above achieved data, the results for the Residual Mix, as well as for total generated electricity and issued I-RECs for China 2021 are presented in Figure 9 and Table 5.

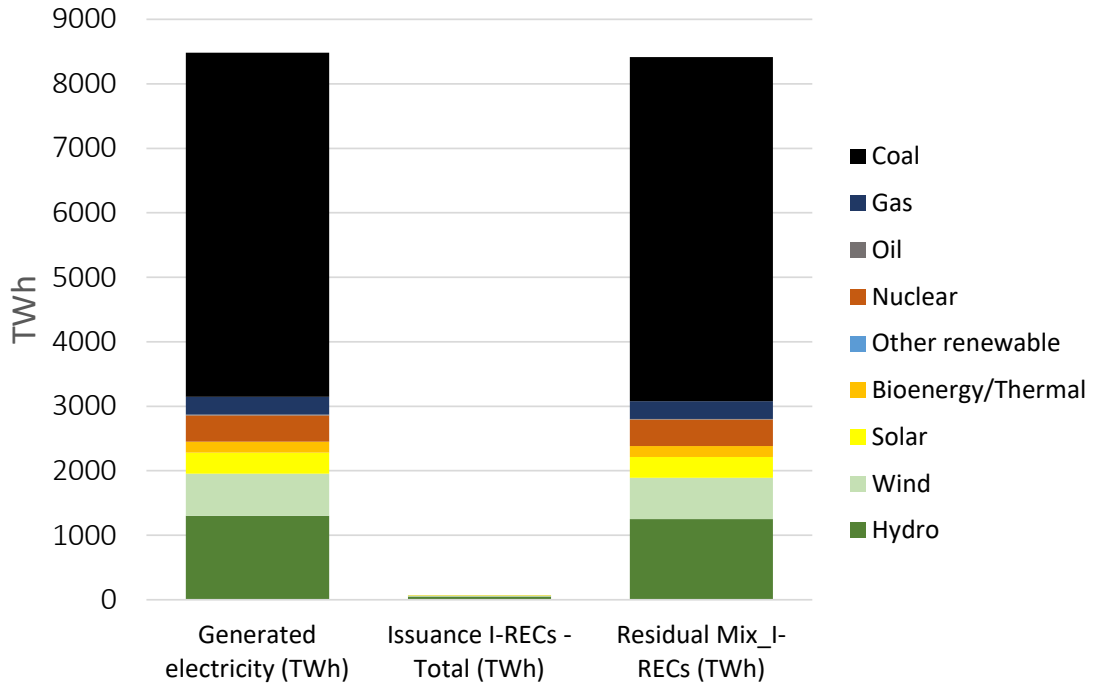

Figure 9 Residual Mix in terms of volume and energy sources for China 2021

Table 5 Different energy sources [TWh] in generated electricity, issued I-RECs and Residual Mix for China 2021

	Hydro	Wind	Solar	Bioenergy/Thermal	Other renewable	Nuclear	Oil	Gas	Coal	Total	% of generated
Generated electricity (TWh)	1300.0	655.6	327.0	169.9	0.0	407.5	12.3	272.6	5339.1	8484.0	
Issuance I-RECs - Total (TWh)	49.6	16.2	1.0	0.4	0.0	0.0	0.0	0.0	0.0	67.2	0.8 %
Residual Mix_I-RECs (TWh)	1250.4	639.4	326.0	169.6	0.0	407.5	12.3	272.6	5339.1	8416.8	99.2 %

As seen in Figure 9 and Table 5, the issued and Residual Mix volumes represent 0.8% and 99.2% of the total generated volume, respectively. The issued volume also represents 2.7% of generated renewable electricity.

China has also an additional tracking instrument (National Green Certificate Sales) beyond I-REC. However, the issued volume in this system is small, only 0.58 TWh in 2021. As detailed data for distribution of the issued volume into different energy sources is not available, this volume is excluded from Figure 5 and Table 3. When adding this issued volume to the issued I-REC volume, the total issued volume becomes 67.8 TWh. Since the extra issued volume is that small compared to the issued I-RECs, the issued and Residual Mix volumes still represent 0.8% and 99.2% of the total generated volume, respectively.

4.2 Additional assumption tests for China 2021

Chapters 4.2.1 and 4.2.2 describe the recommended procedures for verifying the potential impact of the assumptions for the modified calculation method.

It should be noted that the assessments of checkpoints 1 and 2 are based on I-RECs data only, not including data from the other tracking mechanism. The reason for this is lack of data for the issued volume separated into different energy sources and lack of redemption data from (name).

4.2.1 Checkpoint 1, China vintage year 2021: The volume of unredeemed I-RECs

As described in 4 in Raadal and Mooselu (2023), the Residual Mixes are suggested to be published maximum one year after end of generation year (2021). According to Equation 5 in Raadal and Mooselu (2023), the volume of issued but unredeemed I-RECs (vintage X) in country A by end of year X+1 is expressed as follows:

$$Issued\ unredeemed\ I\text{-}RECs_X = National\ Issued\ Volume_{X+1} - R_{Na,\ X+1} - R_{E,\ X+1}$$

When applying this equation for China for vintage year 2021 it turns out as follows:

$$Issued\ unredeemed\ I\text{-}RECs_{2021} = National\ Issued\ Volume_{2022} - R_{Na,\ 2022} - R_{E,\ 2022}$$

Where:

National Issued Volume $_{2022}$ =	Total issued I-RECs for electricity generated in China in 2021 by the end of 2022 (MWh)
$R_{Na,\ 2022}$: Redeemed National$_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of year 2022, issued and redeemed in China (MWh)
$R_{E,\ 2022}$: Redeemed exported$_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of 2022, issued in China and redeemed in another country (MWh)

Based on data provided by I-REC and the equation above, the calculated volume, per 31st of December 2022, of unredeemed I-RECs generated in China in 2021 is 39.077 TWh (see calculation and Figure 10 below).

$$Issued\ unredeemed\ I\text{-}RECs_{2021} = 67.207\ TWh - 26.400\ TWh - 1.730\ TWh = 39.077\ TWh$$

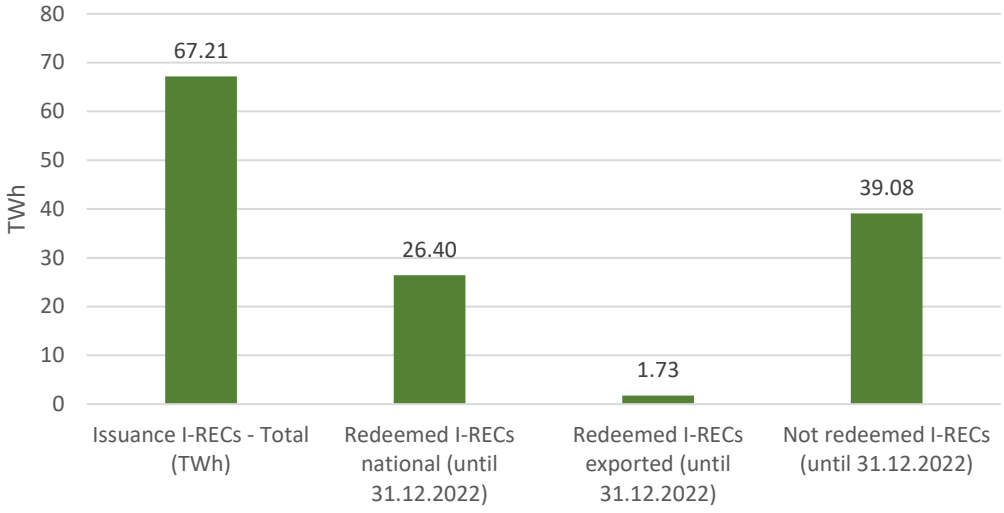

Figure 10 Unredeemed I-RECs (vintage 2021 China) by end of 2022.

The gap between issued and unredeemed I-RECs represents 58 % of total issued volume. The same gap only represents 0.46% of both the total generated electricity and Residual Mix volumes in China 2021. The reason for this is that the issued volume only represents 0.8% of total generation. This shows that using the simplification of assuming all I-RECs to be redeemed still seems reasonable as the impact on the Residual Mix can be assumed negligible. It is also worth mentioning that the issued I-RECs still can be redeemed after the date of publication, which might move the actual Residual Mix towards the calculated one.

4.2.2 Checkpoint 2, China vintage year 2021: Surplus/deficit of attributes

Based on Equation 6 in Raadal and Mooselu (2023), the untracked volume for China in 2021 is calculated as follows:

$$Untracked\ Electricity\ Consumption_X = National\ Generation\ Volume_X - R_{Na,\ X+1} - R_{I,\ X+1}$$

When applying this equation for China for vintage year 2021 it turns out as follows:

$$Untracked\ Electricity\ Consumption_{2021} = National\ Generation\ Volume_{2021} – R_{Na,\ 2022} - R_{I,2022}$$

Where:

National Generation Volume$_{2021}$ =	Generated electricity in 2021 in China (MWh)
$R_{Na,\ 2022}$: Redeemed National $_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of 20221, issued and redeemed in China (MWh)
$R_{I,\ 2022}$: Redeemed imported $_{2022}$ =	Total redeemed I-RECs for electricity generated in 2021 by the end of year 2022, issued in another country and redeemed in China (MWh)

Based on data provided by I-REC and the equation above, the Untracked Electricity Consumption in China 2021 (per December 31st, 2022), is calculated to 8,457.599 TWh (see calculation and Figure 11 below). Again, it should be noted that only I-RECs are included in the calculations as there are no official redemption data for the other tracking instrument.

$Untracked\ Consumption_{2021}$ = 8,484.020 *TWh – 26.400 TWh – 0.021 TWh* = 8,457.599 *TWh.*

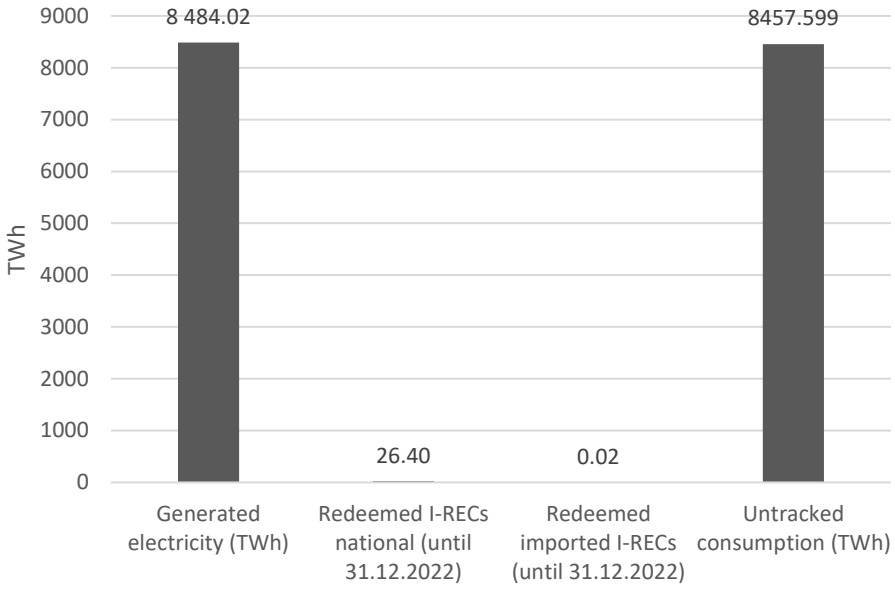

Figure 11 Untracked consumption 2021 in China by end of 2022.

According to Equation 7 in Raadal and Mooselu (2023), the deficit of attributes for Untracked consumption in China (vintage 2021) is calculated to 42,516 MWh (see calculation an Figure 12 below).

Surplus/deficit of attributes = National Residual Mix$_{yearX}$ - Untracked Consumption$_{yearX}$

Surplus/deficit of attributes = 8,416.813 TWh – 8,457.599 TWh = - 40.786 MWh

The same value applies when using Equation 8 in Raadal and Mooselu (2023) for calculating the surplus/deficit of attributes:

Surplus/Deficit = $R_{I, X+1}$ - $R_{E, X+1}$ – I_{NR} = 0.021 TWh – 1.730 TWh – 39.077 TWh = -40.786 TWh

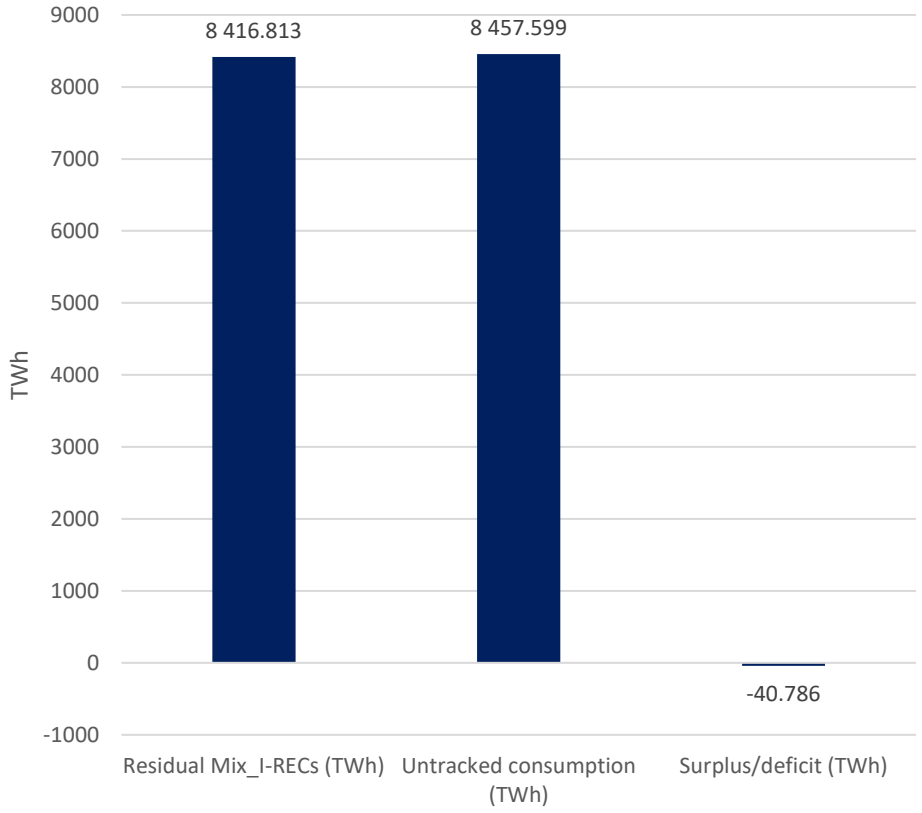

Figure 12 Deficit of attributes (vintage 2021 China) based on Residual Mix and Untracked consumption by end of 2022.

Figure 12 shows that there is a deficit of attributes for the untracked consumption of 40.786 TWh. This volume represents 0.5% of the untracked consumption in China in 2021. The deficit is mainly caused by the unredeemed I-RECs (I_{NR} = 39.077 TWh, as seen above), which are withdrawn in the Residual Mix but not in the Untracked consumption. However, as long as the attribute deficit still is low compared to the untracked consumption, the simplification of the methodology seems reliable.

4.3 Direct CO_2 emission factor for the Chinese Residual Mix 2021

The calculated emission factor for the national Residual Mix is calculated for the issued volume which includes both I-RECs and the other tracking instrument (National Green Certificate Sales), in total 67.8 TWh, which means a Residual Mix volume of 8416.2 TWh.

As presented for Brazil and Chile in chapters 2.3and 3.3, the direct CO_2 emission factor for the national Residual Mix can be calculated in two different ways dependent on the availability of data, as given by Equations 9 and 10 in Raadal and Mooselu (2023).

1. Based on the national emission factor (EF_{Na})

$EF_{RM} = EF_{Na}$ * Volume Total generation [TWh]/Volume Residual Mix [TWh]
= 0.581 Mt CO_2/TWh * 8484.0 TWh/8416.2 TWh = 0.586 Mt CO_2/TWh = 0.586 kg CO_2/kWh

2. Based on specific emission factors for each energy source in the Residual Mix

$$EF_{RM} = \frac{\sum_{k=1}^{n} kg\ CO2\ per\ kWh_{energy\ source\ k} * kWh_{energy\ source\ k}}{\text{Volume Residual Mix [kWh]}}$$

where k is the number of energy sources in the Residual Mix.

Based on the above equation and emission factors per energy source from Annex 3 in AIB (Association of Issuing Bodies) (2023), the direct CO_2 emission factor for the Chinese Residual Mix 2021 is calculated. This is presented in Table 6.

Table 6 Direct emission factor [kg CO_2/kWh] for the Chinese Residual Mix 2021.

Chinese Residual Mix 2021	Hydro	Wind	Solar	Bioenergy/ Thermal	Other renewable	Nuclear	Oil	Gas	Coal	Total
Residual Mix [TWh]*	1 250.40	639.39	325.97	169.56	0.00	407.50	12.25	272.60	5 339.14	8416.24
Emission factor per energy source [kg CO2/kWh]	0	0	0	0	0	0	0.77	0.44	0.86	
Total emissions [Mtonn CO2]	0	0	0	0	0	0	9.40	118.85	4602.34	4730.59
Emission factor Residual Mix [kg CO2/kWh]										0.562

* The total volume includes 0.6 TWh from the other tracking instrument.

As seen in Table 6, the direct emission factor for the Chinese Residual Mix 2021 is 0.562 kg CO_2/kWh, hence some lower than the calculated emission factor based on approach 1 above.

5 References

AIB (Association of Issuing Bodies). (2023). *European Residual Mixes. Results of the calculation of Residual Mixes for the calendar year 2022. Version 1.0, 2023-06-01* (Version 1.0, 2023-06-01). Retrieved from https://www.aib-net.org/sites/default/files/assets/facts/residual-mix/2022/AIB_2022_Residual_Mix_Results_.pdf

Raadal, H. L., & Mooselu, M. G. (2023). *Residual Mix methodology for I-REC issuing countries* (OR.15.23). Retrieved from

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