Extraction of Tannins from Yellow Birch: Enhanced Process for Water Conservation and Energy Savings

Adrien Faye*[1], Alfred Leung[2], Seymour Guyot-Reeb[1], Minh Tan Ton-That[1], Désiré Chimeni-Yomeni[1], Hongbo Li[1], Karen Stoeffler[1], Damien Maillard[1], Marzouk Benali[3]

[1]*National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, QC J4B 6Y4*

[2]*National Research Council of Canada, 6100 Avenue Royalmount, Montréal, QC H4P 2R2*

[3]*Natural Resources Canada, CanmetENERGY, 1615 Lionel-Boulet Boulevard, Varennes, QC J3X 1P7*

*Corresponding author: Adrien.Faye@cnrc-nrc.gc.ca, Tel. +1 450 641 5172

Supporting information

1. Water and energy consumption for tannin extraction from 1 kg of dried bark using the hot water extraction method

1.1 Water consumption

Moisture of bark = 30%
Mass of bark with moisture used per batch = 0.80 kg corresponding to 0.56 kg of dried bark and 0.24 kg of water
Water / dried bark ratio = 2.5, therefore the mass of water used for the extraction = (2.5 * 0.56 kg) + 0.24 kg = 1.64 kg

Mass of water required for 1 kg of dried bark = 1.64 / 0.56 = 2.93 kg

For 0.56 kg of dried bark, 1.2 kg of hot water was required for the residue washing
For 1 kg of dried bark, the mass of water required for the residue washing = 1.2 / 0.56 ~ 2.15 kg

The water consumption for 1 kg of dried bark = 2.93 + 2.15 = **5.08 kg**

1.2 Energy consumption

1.2.1 Chopping step

A chopper machine Pierret G28L1 with a power of 4 kW was used for the chopping step.
145.7 kg of dried bark were chopped in 1.33 hour

Energy consumption for the chopping step = 4 * 1.33 /145.7 ~ **0.04 kWh/kg**

1.2.2 Grinding step

A granulator Mo-Di-Tec GPlus with the following characteristics was used for the grinding step.

- Power = 1.5 kW
- Cos(Φ) = 0.87

Energy consumption for the grinding step, Eg = Power * cos(Φ) * hour / mass of bark

Grinding iteration	Mass of dried bark (kg)	Grinding time (min)	Eg (kWh/kg)
1 time	3.25	21.50	**0.15**
2 times	3.30	13.60	0.24
3 times	3.35	12.40	0.32

1.2.3 Extraction step

- Mass heat capacity of water = 4.185 kJ. kg^{-1}. K^{-1}
- Mass heat capacity of bark = 1.500 kJ. kg^{-1}. K^{-1}
- The extraction temperature was fixed at 95°C
- The extraction time was kept at 2 hours
- 1 kJ ~ 0.000278 kWh

- **Energy required for the heating**

The water and the bark were heated from 20°C to 95°C and kept at this temperature for X hours.

Energy required to heat 2.93 kg of water from 20°C to 95°C
= 2.93 * 4.185 * (95-20) * 0.000278 ~ 0.26 kWh

Energy required to heat 1 kg of dried bark from 20°C to 95°C
= 1 * 1.500 * (95-20) * 0.000278 ~ 0.03 kWh

Energy required to heat water and bark for the extraction step using 1 kg of dried bark
= 0.26 + 0.03 = **0.29 kWh**

After extraction, the tannin solution was separated from the bark residue by centrifugation and the residue was washed 2 times using hot water.
For 1 kg of dried bark, the mass of water required for the washing step = 2.15 kg
Energy required to heat water from 20°C to 95°C
= 2.15 * 4.185 * (95-20) * 0.000278 ~ 0.19 kWh

Total energy required to heat water and bark using 1 kg of dried bark
= 0.29 + 0.19 = **0.48 kWh**

- **Energy lost**

A reactor was used during the extraction. It was assumed that, for each hour of extraction, 5% of the energy was lost. Energy lost during 2 hours extraction, El = 0.29 * 2 * 5% ~ **0.03 kWh**
The energy lost during the water heating for the residue washing was negligible.

- **Energy consumed by the mechanical stirrer**

A mechanical stirrer with a power of 87 W was used for the mixing during the extraction.
Energy consumption for the stirrer during 2 hours using 1 kg of dried bark
= 0.087 * 2 ~ **0.18 kWh**

- **Energy consumed during the centrifugation**

A centrifuge with a power of 1.4 kW was used to separate the residue from the tannin solution.
For 1 kg of dried bark, the centrifuge was run during 10 min for the separation therefore the energy consumed = 1.4 * 10 / 60 ~ **0.24 kWh**

Total energy consumption for the extraction step using 1 kg of dried bark
= 0.48 + 0.03 + 0.18 + 0.24 = **0.93 kWh**

1.2.4 Evaporation step

Latent heat of vaporization of water = 2257 kJ/kg
The total mass of water used for the extraction = 5.08 kg
After tannin extraction and separation, 15% of the total mass of water was lost therefore the mass of water to be evaporated to recover the tannin powder = 5.08 – 5.08* 15% ~ 4.32 kg.
The temperature of the tannin solution after separation was 70°C.

To evaporate the water, it is heated until 100°C and transformed into vapor.
Energy required to evaporate the water and to recover the tannin powder. 34.63
= (4.32 * 4.185 * (100 – 70)) + (4.32 * 2257) = 10292.616 kJ
= 10292.616 * 0.000278 ~ **2.86 kWh**

Total energy consumption for tannin extraction from 1 kg of dried bark using the hot water extraction method = 0.04 + 0.15 + 0.93 + 2.86 = **3.98 kWh**

2. Water and energy consumption for the production of 1 kg of tannin

2.1 Hot water extraction method

- **Water consumption for an extraction time of 2 h**

Tannin yield = 2.30 %

Mass of dried bark required for the production of 1 kg of tannin = 100 / 2.30 = 43.48 kg

Mass of required for the production of 1 kg of tannin = mass of dried bark required for the production of 1 kg of tannin *multiplied* by the mass of water used for the extraction of 1 kg of dried bark = 43.48 * 5.08 ~ **220.88 kg**

- **Energy consumption for an extraction time of 2 h**

Energy consumption for the chopping step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the chopping energy for 1 kg of dried bark = 43.48 * 0.04 ~ **1.74 kWh**

Energy consumption for the grinding step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the grinding energy for 1 kg of dried bark = 43.48 * 0.15 ~ **6.52 kWh**

Energy consumption for the extraction step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the extraction energy for 1 kg of dried bark = 43.48 * 0.93 ~ **40.44 kWh**

Energy consumption for the isolation step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the isolation energy for 1 kg of dried bark = 43.48 * 2.86 ~ **124.35 kWh**

Total energy consumption for the production of 1 kg tannin using the hot water extraction method = 1.74 + 6.52 + 40.44 + 124.35 = **173.05 kWh**

2.2 Method 1: Combination of the hot water extraction and the ultrasound assisted extraction

- **Water consumption for an extraction time of 1 h**

Tannin yield = **3.20 %**

Mass of the dried bark required for the production of 1 kg of tannin = 100 / 3.20 ~ **31.25 kg**

Water consumption for the production of 1 kg of tannin = mass of dried bark required for the production of 1 kg of tannin *multiplied* by the mass of water used for the extraction of 1 kg of dried bark = 31.25 * 5.08 ~ **158.75 kg**

- **Energy consumption for an extraction time of 1 h**

Energy consumption for the chopping step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the chopping energy for 1 kg of dried bark = 31.25 * 0.04 ~ **1.25 kWh**

Energy consumption for the grinding step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the grinding energy for 1 kg of dried bark = 31.25 * 0.15 ~ **4.69 kWh**

Energy consumption for the extraction step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the extraction energy for 1 kg of dried bark using Method 1

Calculation of the extraction energy for1 kg of dried bark using Method 1
The extraction time of Method 1 is divided into two parts:

- Extraction time of 0.75 hour using the hot water extraction method
- Extraction time of 0.25 hour using an ultrasound probe with a power of 0.04 kW

Energy required for the heating (water and bark) is the same as that of the hot water method = 0.48 kWh

Energy consumed by the mechanical stirrer = 0.087 * 0.75 ~ 0.07 kWh
Energy lost = 0.29 * 0.75 * 5% ~ 0.01 kWh
Energy consumed by the ultrasound probe = 0.04 * 0.25 / 0.56 ~ 0.02 kWh
Energy consumed by the centrifuge = 0.24 kWh

Energy consumption for the extraction step for 1 kg of dried bark using Method 1
= 0.48 + 0.07 +0.01 + 0.02 + 0.24 = 0.82 kWh

Energy consumption for the extraction step for 31.3 kg of dried bark using Method 1
= 31.25 * 0.82 ~ **25.63 kWh**

Energy required for the isolation step = 2.86 *31.25 ~ **89.38 kWh**

Total energy consumption for the production of 1 kg of tannin using Method 1
= 1.25 + 4.69 + 25.63 + 89.38 = **120.95 kWh**

- **Water consumption for an extraction time of 2 h**

Tannin yield = **3.50 %**

Mass of the dried bark required for the production of 1 kg of tannin = 100 / 3.50 ~ **28.57 kg**

Mass of water used for the production of 1 kg of tannin = mass of dried bark required for the production of 1 kg of tannin *multiplied* by the mass of water used for the extraction of 1 kg of dried bark = 28.57 * 5.08 ~ **145.14 kg**

- **Energy consumption for an extraction time of 2 h**

Energy consumption for the chopping step = Mass of dried bark required to produce 1 kg of tannin *multiplied* by the chopping energy for 1 kg of dried bark = 28.57 * 0.04 ~ **1.14 kWh**

Energy consumption for the grinding step = Mass of dried bark required to produce 1 kg of tannin *multiplied* by the grinding energy for 1 kg of dried bark = 28.57 * 0.15 ~ **4.29 kWh**
Energy consumption for the extraction step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the extraction energy for 1 kg of dried bark using Method 1

The extraction time of the method 1 is divided into two parts:
- Extraction time of 1.75 hour using the hot water method
- Extraction time of 0.25 hour using a ultrasound probe with a power of 0.04 kW

Energy required for the heating is the same as the hot water method = 0.48 kWh
Energy consumed by the mechanical stirrer = 0.087 * 1.75 ~ 0.16 kWh
Energy lost = 0.29 * 1.75 * 5% ~ 0.03 kWh
Energy consumed by the ultrasound probe = 0.04 * 0.25 / 0.56 ~ 0.02 kWh
Energy consumed by the centrifuge = 0.24 kWh

Energy consumption for the extraction step for 1 kg of dried bark using Method 1
= 0.48 + 0.16 + 0.03 + 0.02 + 0.24 = 0.93 kWh

Energy consumption for the extraction step using 28.57 kg of dried bark = 28.57 * 0.93 ~ **26.57 kWh**
The energy required for the isolation step = 2.86 * 28.47 = **81.71 kWh**

Total energy consumption for the production of 1 kg of tannin using Method 1
= 1.14 + 4.29 + 26.57 + 81.71 = **113.71 kWh**

2.3 Method 2 : Extract solution of the first extraction is recycled 1 time using the hot water method

2.3.1 Water consumption for an extraction time of 2 h

Tannin yield = **2.20 %**
Mass of the dried bark required for the production of 1 kg of tannin = 100 / 2.20 ~ 45.45 kg
Mass of water required for the first extraction = 45.45 * 5.08 ~ 230.89 kg

After the separation of the tannin solution from the bark residue, 15% of the initial mass of the water was not recovered. Therefore a mass of hot water equivalent to 230.89 * 15% ~ 34.63 kg was added to the collected tannin solution after separation and used as solvent in a second extraction.
The hot water used to wash the residue of the first extraction was also used to wash the residue of the second extraction therefore the mass of water required for the second extraction = 0.
Total mass of water used for the production of 1 kg of tannin when the extract solution is reused 1 time = (230.89 + 34.63) / 2 ~ **132.76 kg**

Estimation E1: Extract solution of the first extraction recycled 2 times using the hot water method
It was assumed that the tannin yield obtained when the extract solution is reused 2 times is the same as when the extract solution is reused 1 time, therefore:
Tannin yield = 2.20 %
Mass of the dried bark required for the production of 1 kg of tannin = 45.45 kg
Mass of water used for the first extraction = 230.89 kg
Additional mass of water used for the second extraction = 34.63 kg
Additional mass of water used for the third extraction is the same as that of the second extraction = 34.63 kg
The hot water used to wash the residue of the first and second extraction was also used to wash the residue of the third extraction therefore the mass of water required for the residue washing of the third extraction = 0.
Total mass of water used for the production of 1 kg of tannin when the extract solution is reused 2 times = (230.89 + 34.63 + 34.63) / 3 = **100.05 kg**

Estimation E2: Extract solution of the first extraction recycled 3 times using the hot water method

It was assumed that the tannin yield obtained when the extract solution is reused 3 times is the same as when the extract solution is reused 1 time, therefore:
Tannin yield = 2.20 %
Mass of water used for the first extraction = 230.89 kg
Additional mass of water used for the second extraction = 34.63 kg
Additional mass of water used for the third extraction = 34.63 kg
Additional mass of water used for the fourth extraction is the same as that of the third extraction = 34.63 kg
The hot water used to wash the residue of the first, second and third extraction was also used to wash the residue of the fourth extraction therefore the mass of water required for the residue washing of the fourth extraction = 0.
Total mass of water used for the production of 1 kg of tannin when the extract solution is reused 3 times = (230.89 + 34.63 + 34.63 + 34.63) / 4 ~ **83.70 kg**

2.3.2 Energy consumption for an extraction time of 2 h

Energy consumption for the chopping step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the chopping energy for 1 kg of dried bark = 45.45 * 0.04 ~ **1.82 kWh**

Energy consumption for the grinding step = Mass of dried bark required for the production of 1 kg of tannin *multiplied by the* grinding energy for 1 kg of dried bark = 45.45 * 0.15 ~ **6.82 kWh**

Energy consumption for the extraction step = (Energy consumption for the first extraction + Energy consumption for the second extraction) / 2

Energy consumption of the first extraction = 0.93 * 45.45 = 42.27 kWh

Calculation of the energy consumption for the second extraction
34.63 kg of hot water were added during the second extraction
Energy required to heat 34.63 kg of water = 34.63 * 4.185 * (95 – 20) * 0.000278 ~ 3.02 kWh

Energy required to heat 1 kg of dried bark = 0.03 kWh
Energy required to heat 45.45 kg of bark = 45.45 * 0.03 ~ 1.36 kWh

The recovered tannin solution of the first extraction needs to be heated from 70°C to 95°C because during the separation step the temperature drops.
Energy required to heat the recovered tannin solution
= (230.89 – 230.89 * 15%) * 4.185 * (95 – 70) * 0.000278 ~ 5.71 kWh
The hot water used to wash the residue of the first extraction was also used to wash the residue of the second extraction therefore the water heating energy for the residue washing for the second extraction = 0.
Energy consumption during the second extraction step (losses, mechanical stirrer and centrifuge) = 45.45 * (0.03 + 0.18 + 0.24) ~ 20.45 kWh

Total energy consumption of the second extraction = 3.02 + 1.36 + 5.71 + 20.45 ~ 30.54 kWh

Energy consumption for the extraction step when the extract solution is reused 1 time
= (42.27 + 30.54) / 2 ~ **36.41 kWh**

Energy required to evaporate 34.63 kg of water
= (34.63 * 4.185 * (100 – 70)) + (34.63 * 2257) = 82507.7065 kJ
= 82507.7065 kJ * 0.000278 ~ 22.94 kWh

Energy required for the isolation step when the extract solution is reused 1 time
= (2.86 * 45.45 + 22.94) / 2 ~ **76.46 kWh**

Total energy consumption for the production of 1 kg of tannin when the extract solution is reused 1 times = 1.82 + 6.82 + 36.41 + 76.46 = **121.51 kWh**

Estimation E1: Extract solution of the first extraction recycled 2 times using the hot water method
Energy consumption for the extraction step = (Energy consumption for the first extraction step + Energy consumption for the second extraction step + Energy consumption for the third extraction step) / 3

Energy consumption of the first extraction = 42.27 kWh
Energy consumption for the second extraction = 30.54 kWh
Energy consumption for the third extraction is the same as that of the second extraction = 30.54 kWh

Energy consumption for the extraction step = (42.27 + 30.54 + 30.54) / 3 ~ **34.45 kWh**

Energy required to evaporate 34.63 kg of water
= (34.63 * 4.185 * (100 – 70)) + (34.63 * 2257) = 82507.7065 kJ
= 82507.7065 kJ * 0.000278 ~ 22.94 kWh

Energy required for the isolation step = (2.86 * 45.45 + 22.94 + 22.94) / 3 ~ **58.62 kWh**

Total energy consumption for the production of 1 kg of tannin when the extract solution is reused 2 times = 1.82 + 6.82 + 34.45 + 58.62 = **101.71 kWh**

Estimation E2: Extract solution of the first extraction recycled 3 times using the hot water method
Energy consumption for the extraction step = (Energy consumption for the first extraction step + Energy consumption for the second extraction step + Energy consumption for the third extraction step + Energy consumption for the fourth extraction step) / 4

Energy consumption of the first extraction step = 42.27 kWh
Energy consumption for the second extraction = 30.54 kWh
Energy consumption for the third extraction = 30.54 kWh

Energy consumption for the fourth extraction is the same as that of the third extraction = 30.54 kWh

Energy consumption for the extraction step = (42.27 + 30.54 + 30.54 + 30.54) / 4 ~ **33.47 kWh**

Energy required to evaporate 34.63 kg of water
= (34.63 * 4.185 * (100 – 70)) + (34.63 * 2257) = 82507.7065 kJ
= 82507.7065 kJ * 0.000278 ~ 22.94 kWh
Energy required for the isolation step = (2.86 * 45.45 + 22.94 + 22.94 + 22.94) / 4 ~ **49.70 kWh**

Total energy consumption for the production of 1 kg of tannin when the extract solution is reused 3 times = 1.82 + 6.82 + 33.47 + 49.70 = **91.81 kWh**

2.3 Method 3 : Extract solution recycled 1 time using Method 1

2.3.1 Water consumption for an extraction time of 2 h

Tannin yield = **2.60 %**

Mass of the dried bark required for the production of 1 kg of tannin = 100 / 2.60 ~ **38.46 kg**

Mass of water used for the first extraction = 38.46 * 5.08 ~ 195.38 kg
After the separation of the tannin solution from the bark residue, 15% of the initial mass of the water was not recovered. Therefore a mass of hot water equivalent to 195.38 * 15% ~ 29.31 kg was added to the collected hot tannin solution and used as solvent for a second tannin extraction.
The hot water used to wash the residue of the first extraction was also used to wash the residue of the second extraction therefore the water heating energy for the residue washing of the second extraction = 0.
Mass of water used for the production of 1 kg of tannin when the extract solution is reused 1 time using Method 1 = (195.38 + 29.31) / 2 = **112.35 kg**

Estimation E3: Extract solution of the first extraction recycled 2 times using Method 1
It has been assumed that the tannin yield obtained when the extract solution is reused 2 times is the same as when the extract solution is reused 1 time, therefore:
Tannin yield = 2.60 %
Mass of the dried bark required for the production of 1 kg of tannin = 100 / 2.60 ~ 38.46 kg

Mass of water used for the first extraction = 195.38 kg
Additional mass of water used for the second extraction = 29.31 kg
Additional mass of water used for the third extraction is the same as that of the second extraction = 29.31 kg
The hot water used to wash the residue of the first and second extraction was also used to wash the residue of the third extraction therefore the mass of water required for the residue washing of the third extraction = 0.
Mass of water used for the production of 1 kg of tannin when the extract solution is reused 2 times = (195.38 + 29.31 + 29.31) / 3 = **84.67 kg**

Estimation E4: Extract solution of the first extraction recycled 3 times using Method 1
It has been assumed that the tannin yield obtained when the extract solution is reused 3 times is the same as when the extract solution is reused 1 time, therefore:
Tannin yield = 2.60 %
Mass of the dried bark required for the production of 1 kg of tannin = 100 / 2.60 ~ 38.46 kg

Mass of water used for the first extraction = 195.38 kg
Additional mass of water used for the second extraction = 29.31 kg
Additional mass of water used for the third extraction = 29.31 kg
Additional mass of water used for the fourth extraction is the same as that of the third extraction = 29.31 kg
The hot water used to wash the residue of the first, second and third extraction was also used to wash the residue of the fourth extraction therefore the mas of water required for the residue washing of the fourth extraction = 0.
Mass of water used for the production of 1 kg of tannin when the extract solution is reused 3 times = (195.38 + 29.31 + 29.31 + 29.31) / 4 ~ **70.83 kg**

2.3.2 Energy consumption for an extraction time of 2 h

Energy consumption for the chopping step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the chopping energy for 1 kg of dried bark = 38.46 * 0.04 ~ **1.54 kWh**

Energy consumption for the grinding step = Mass of dried bark required for the production of 1 kg of tannin *multiplied* by the grinding energy for 1 kg of dried bark = 38.46 * 0.15 ~ **5.77 kWh**

Energy consumption for the extraction step = (Energy consumption for the first extraction step + Energy consumption for the second extraction step) / 2

Energy consumption of the first extraction = 0.93 * 38.46 = 35.77 kWh

Energy consumption for the second extraction
29.31 kg of hot water were added during the second extraction
Energy required to heat 29.31 kg of water = 29.31 * 4.185 * (95 – 20) * 0.000278 ~ 2.56 kWh

Energy required to heat 1 kg of dried bark = 0.03 kWh
Energy required to heat 38.46 kg of bark = 38.46 * 0.03 ~ 1.15 kWh

The recovered tannin solution of the first extraction needs to be heated from 70°C to 95°C because during the separation step the temperature drops.
Energy required to heat the recovered tannin solution
= (195.38 – 29.31) * 4.185 * (95 – 70) * 0.000278 ~ 4.83 kWh

Energy consumption for the second extraction step (mechanical stirrer, losses, ultrasound, centrifuge) = 38.46 * (0.16 + 0.03 + 0.02 + 0.24) ~ 17.31 kWh

Total energy consumption for the second extraction = 2.56 + 1.15 + 4.83 + 17.31 ~ 25.85 kWh

Energy consumption for the extraction step when the extract solution is reused 1 time using Method 1 = (35.77 + 25.85) / 2 ~ **30.81 kWh**

Energy required to evaporate 34.63 kg of water
= (29.31 * 4.185 * (100 – 70)) + (29.31 * 2257) = 69832.5405 kJ
= 69832.5405 kJ * 0.000278 ~ 19.41 kWh
Energy required for the isolation step when the extract solution is reused 1 time using Method 1 = (2.86 * 38.46 + 19.41) / 2 ~ **64.70 kWh**

Total energy consumption for the production of 1 kg of tannin when the extract solution is reused 1 time using Method 1 = 1.54 + 5.77 + 30.81 + 64.70 = **102.82 kWh**

Estimation E3: Extract solution of the first extraction recycled 2 times using Method 1

Energy consumption for the extraction step = (Energy consumption for the first extraction step + Energy consumption for the second extraction step + Energy consumption for the third extraction step) / 3

Energy consumption for the first extraction = 0.93 * 38.46 = 35.77 kWh
Energy consumption for the second extraction = 25.85 kWh
Energy consumption for the third extraction is the same as that of the second extraction = 25.85 kWh

Energy consumption for the extraction step when the extract solution is reused 2 times using Method 1 = (35.77 + 25.85 + 25.85) / 3 ~ **29.16 kWh**

Energy required for the isolation step using Method 2 = (19.41 + 19.41 + 2.86 * 38.46) / 3 ~ **49.61 kWh**

Total energy consumption for the production of 1 kg of tannin when the extract solution is reused 1 time using Method 1 = 1.54 + 5.77 + 29.16 + 49.61 = **86.08 kWh**

Estimation E4: Extract solution of the first extraction recycled 3 times using Method 1

Energy consumption for the extraction step = (Energy consumption for the first extraction step + Energy consumption for the second extraction step + Energy consumption for the third extraction step + Energy consumption for the fourth extraction step) / 4

Energy consumption for the first extraction = 0.93 * 38.46 = 35.77 kWh
Energy consumption for the second extraction = 25.85 kWh
Energy consumption for the third extraction = 25.85 kWh
Energy consumption for the fourth extraction is the same as that of the third extraction = 25.85 kWh

Energy consumption for the extraction step when the extract solution is reused 2 times using Method 1 = (35.77 + 25.85 + 25.85 + 25.85) / 4 ~ **28.33 kWh**

Energy required for the isolation step using Method 2 = (19.41 + 19.41 + 19.41 + 2.86 * 38.46) / 4 ~ **42.06 kWh**

Total energy consumption for the production of 1 kg of tannin when the extract solution is reused 1 time using Method 1 = 1.54 + 5.77 + 28.33 + 42.06 = **77.70 kWh**