

Supplementary Information

Biomass torrefaction for renewable energy: from physicochemical, bulk properties and flowability to future perspectives and applications

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Figure S1. The co-occurrence clusters with the keywords of the selected articles from Scopus and Web of Science databases.

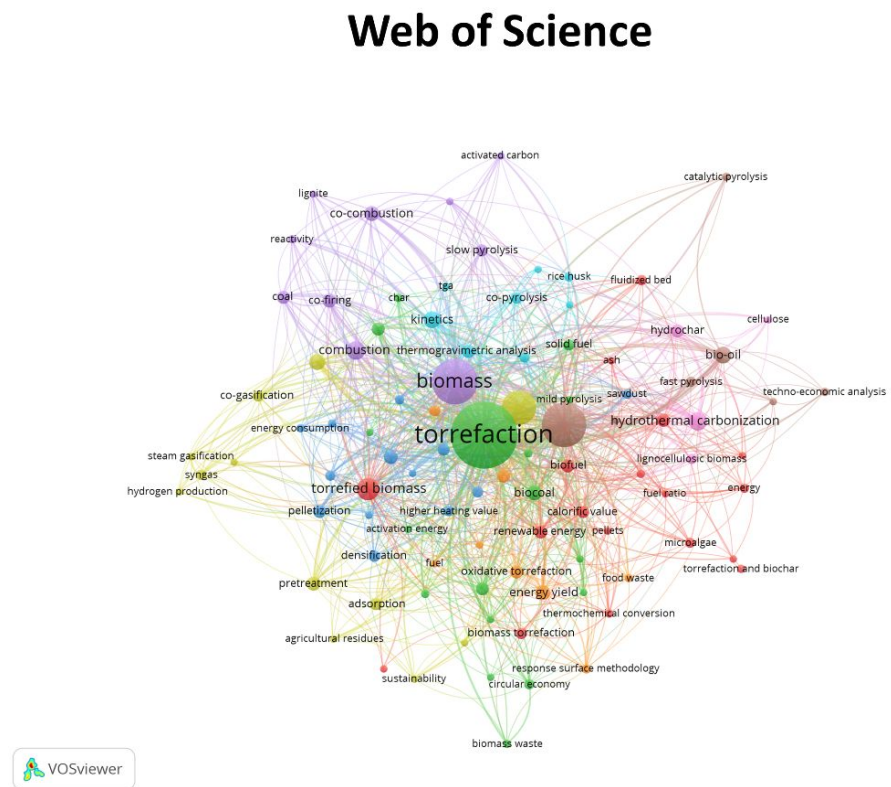
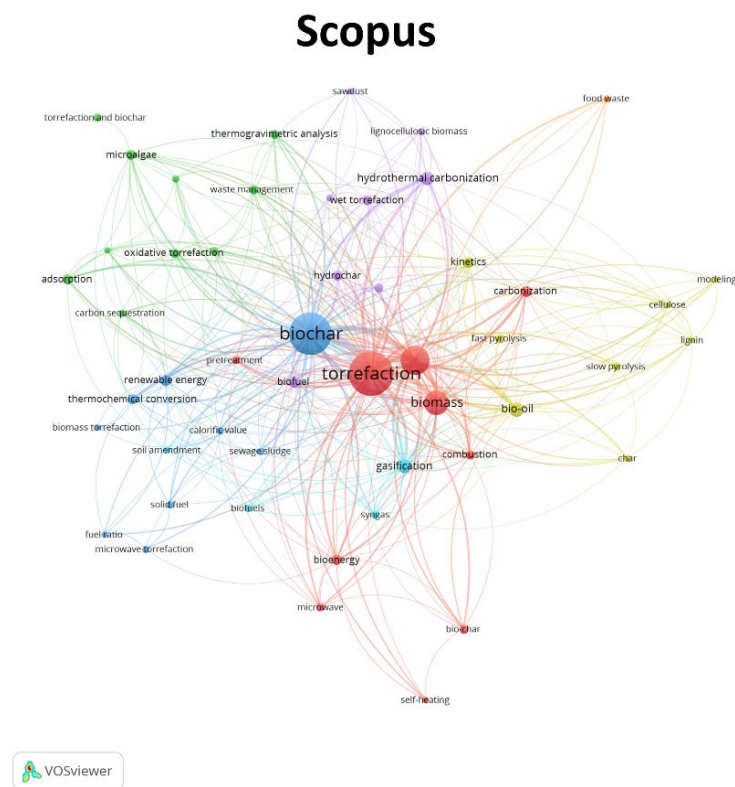


Figure S2. The co-occurrence clusters with the affiliations (countries) of the selected articles from Scopus and Web of Science databases.

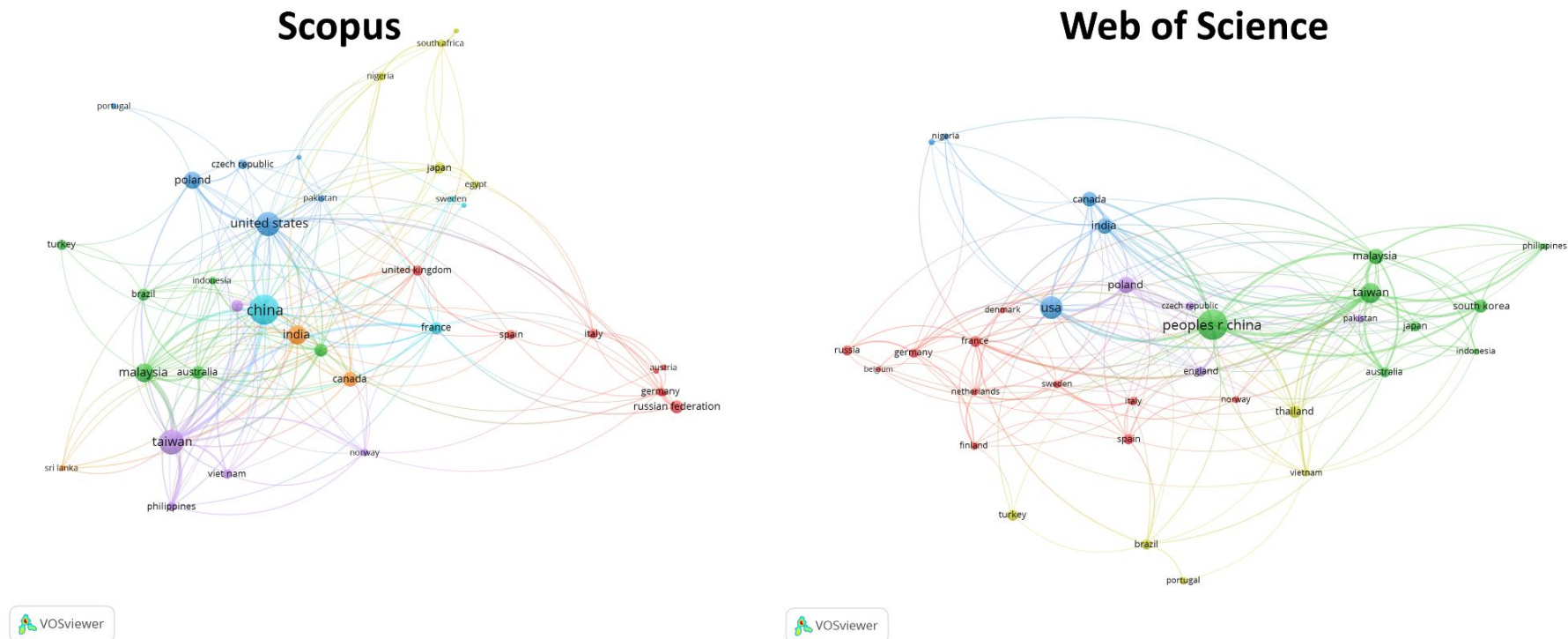


Table S1. Qualitative analysis of physical and bulk properties of raw and torrefied biomass. (ρ_t : true density, ρ_p : particle density, M: Moisture, S: Surface area, PSD: Particle size distribution, ρ_{bulk} : Bulk density, ε : Bed porosity). * Surface area is related to BET measurements, and it also involves mean pore size and pore volume estimation. (x: Yes, o: No)

Author	Year	Size	ρ_t	ρ_p	M	S*	Morphology	PSD	ρ_{bulk}	ε
Soh et al. ¹	2022	x	o	o	o	o	x	o	o	o
Lacombe et al. ²	2024	o	o	x	x	o	o	x	x	x
Xu et al. ³	2019	x	o	o	o	o	x	x	x	o
Panahi et al. ⁴	2019	x	x	o	x	o	x	o	x	x
Liu et al. ⁵	2024	o	o	o	o	x	x	o	o	o
Singh et al. ⁶	2019	x	o	x	o	x	o	o	x	o
Sarker et al. ⁷	2022	o	o	x	o	x	o	o	x	o
Surup et al. ⁸	2020	o	o	x	o	o	x	o	o	o
Szufa et al. ⁹	2020	o	o	o	o	o	x	o	o	o
Chen et al. ¹⁰	2011	x	o	o	o	o	x	x	o	o
Yilmaz et al. ¹¹	2022	o	o	x	x	o	o	o	x	o
Tu et al. ¹²	2022	o	o	o	o	x	o	o	o	o
Singh et al. ¹³	2020	x	o	x	x	o	x	x	x	x
Trubetskaya et al. ¹⁴	2019	x	x	o	x	x	x	o	o	o
Sanchez et al. ¹⁵	2016	x	x	o	x	o	o	x	x	o
Sarker et al. ¹⁶	2021	o	o	x	x	o	x	x	x	o
Pachom-Morales ¹⁷	2020	x	o	x	o	o	o	o	o	o

Costa and Costa ¹⁸	2015	o	o	o	x	o	x	x	o	o
Sanchez et al. ¹⁹	2017	x	x	o	x	o	o	x	x	o
Phanphanich ²⁰	2011	x	x	o	x	x	o	x	x	o
Ghiasi et al. ²¹	2014	x	o	x	x	o	o	o	o	o
Emadi ²²	2017	x	x	x	x	x	x	x	x	x
Riaz et al. ²³	2022	x	o	x	x	o	o	o	x	o
Nhuchhen ²⁴	2016	x	o	o	x	o	o	o	x	o
Onyenwoke ²⁵	2023	x	o	x	x	o	o	o	x	o
Kwapinska ²⁶	2015	x	o	x	x	o	o	x	x	o
Medina ²⁷	2015	x	x	o	x	x	x	x	x	o
Manouchehrinejad ²⁸	2018	x	o	o	x	o	o	x	x	o
Wang et al. ²⁹	2018	x	o	o	x	o	o	o	x	o
Gaitán-Alvarez ³⁰	2017	o	o	o	x	o	o	o	x	o
Sobol et al. ³¹	2023	o	o	x	o	x	o	o	x	x
Ullah et al. ³²	2023	o	o	o	o	o	x	o	o	o
Vold et al. ³³	2015	o	o	x	x	o	x	o	o	o
Cao et al. ³⁴	2015	x	o	x	o	o	x	x	o	o
Yang ³⁵	2023	o	o	o	x	x	x	o	o	o
Rousset ³⁶	2012	x	o	x	o	o	o	o	o	o
Tsai ³⁷	2013	x	x	o	x	o	x	o	o	o

Yang ³⁸	2017	x	o	o	x	x	x	x	x	x	x
da Silva et al. ³⁹	2019	o	o	o	x	x	x	o	o	o	o
Na ⁴⁰	2015	x	o	o	x	o	o	x	o	o	o
Isemin ⁴¹	2021	x	o	o	o	x	o	x	x	x	o
Bridgeman et al. ⁴²	2010	x	o	o	x	o	o	x	o	o	o
Dyjakon ⁴³	2020	o	o	x	x	o	o	o	x	x	x
Ilango ⁴⁴	2016	o	o	o	x	o	o	o	o	o	o
Vold et al. ³³	2014	x	x	o	x	o	o	o	x	x	x
Rago et. al. ⁴⁵	2018	o	o	o	x	o	o	o	x	o	o
Agu et al. ⁴⁶	2021	x	o	x	x	o	x	o	x	o	o
Khalsa et al. ⁴⁷	2016	x	o	o	o	o	o	x	x	o	o
Gasco et al. ⁴⁸	2018	x	o	o	o	o	o	x	x	x	x
Grycova et al. ⁴⁹	2023	o	o	x	x	o	o	o	x	o	o
Ali and Watson ⁵⁰	2016	x	o	o	x	o	o	x	x	o	o
Basu et al. ⁵¹	2013	x	x	x	x	o	o	o	x	o	o
Zahra et al. ⁵²	2023	x	o	o	x	o	o	x	o	o	o

Table S2. Qualitative analysis of chemical and thermal properties of raw and torrefied biomass. (HHV: Higher heating value, FTIR: Fourier transform infrared spectroscopy, XRD: X-ray diffraction, XPS: X-ray photoelectron spectroscopy). (x: Yes, o: No)

Author	Year	Biomass	Proximate	Ultimate	HHV	FTIR	XRD	XPS
Soh et al. ¹	2022	Oil palm trunks (OPT)	o	x	x	x	x	o
Lacombe et al. ²	2024	Olive stones and oak	o	x	x	o	o	o
Alizadeh et al. ⁵³	2022	Wood sawdust	x	x	x	o	o	o
Panahi et al. ⁴	2019	Various	x	o	o	o	o	o
Liu et al. ⁵	2024	Bamboo dust	o	x	o	x	o	x
Singh et al. ⁶	2019	Acacia nilotica	x	x	x	x	x	o
Sarker et al. ⁷	2022	Oat hull, canola hull and mustard meal	x	x	x	x	o	o
Surup et al. ⁸	2020	Olive pulp	x	x	x	x	o	o
Szufa et al. ⁹	2021	Micanthus	x	x	o	o	o	o
Chen et al. ¹⁰	2011	Bamboo, banyan and willow	x	x	x	o	o	o
Yilmaz et al. ¹¹	2022	Palm pruning residues	x	x	x	o	o	o
Tu et al. ¹²	2022	Camellia shell	x	x	x	o	o	o
Singh et al. ¹³	2020	Acacia nilotica	x	x	x	o	o	o

Trubetskaya et al. ¹⁴	2019	Woodchips and olive stones	x	x	x	o	x	o
Sanchez et al. ¹⁵	2016	Olive stones	x	x	x	x	o	o
Sarker et al. ¹⁶	2021	Canola residue	x	x	x	x	x	o
Costa and Costa ¹⁸	2015	Pine shells, olive stones, wheat straw	x	x	x	o	o	o
Sanchez et al. ¹⁹	2017	Avocado seeds	x	x	x	x	o	o
Phanphanich ²⁰	2011	Woodchips and forest residues	x	x	x	o	o	o
Ghiasi et al. ²¹	2014	Woodchips	x	x	x	o	o	o
Nhuchhen ²⁴	2016	Yellow poplar	x	x	o	o	o	o
Onyenwoke ²⁵	2023	Oat straw	x	x	x	o	o	o
Manouchehrinejad ²⁸	2018	Wood chips and pellets	x	o	x	o	o	o
Wang et al. ²⁹	2018	Spruce-pine-fir sawdust	x	x	x	o	o	o
Sobol et al. ³¹	2023	Various	x	o	x	o	o	o
Ullah et al. ³²	2023	Orange peel	x	x	x	x	x	o
Cao et al. ³⁴	2015	Wood sawdust	x	x	x	o	o	o
Yang ³⁵	2023	Spent coffee grounds	x	x	x	x	o	o
Tsai ³⁷	2013	Coffee residues	x	x	x	o	o	o

Yan ⁵⁴	2017	Bamboo	x	o	o	x	o	o
da Silva et al. ³⁹	2019	Various	x	x	o	x	o	o
Na, Ahn and Lee ⁴⁰	2015	Yellow poplar	x	x	x	x	o	o
Bridgeman et al. ⁴²	2010	Willow and miscanthus	x	x	x	o	o	o
Ilango and Lefebvre ⁴⁴	2016	Simulated human feces	x	x	o	x	o	o
Rago, Surroop and Mohee ⁴⁵	2018	Textile waste	x	x	x	o	o	o
Zahra et al. ⁵²	2023	Algae biomass	x	x	x	o	o	o

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