Environmental Protection in Enhanced Oil Recovery and its Waste and Effluents Treatment: A Critical Patent-Based Review of BRICS and Non-BRICS (2004–2023)

SUPPLEMENTARY MATERIAL

TABLES

Table S1: Equivalence of EOR and environmental protection (EOR&Env) technological methods between patent and article searches.

EOR&Env method	IPC	Keywords
GEOR - (Polymers OR macrocompounds) and Surfactants	(C09K-008/588 OR C09K-008/88) AND C09K-008/584	(surfactant* OR (surface activ*) OR tensoactiv* OR ("surface active agent*")) AND (polymer* OR (macromolecular compound*))
GEOR - Combustion in situ	E21B-043/16, 243, 247, 248	(combustion*
GEOR - Fracturing, fracture reinforcement, interconnecting wells	E21B-043/16, 17, 26, 267	("forming cervice*" or fractur* or fracking*) OR ((fractur* and reinforce*) OR ((fracturing OR fracture or hydraulic fracture OR fracking) AND ("interconect* wells" OR "conect* wells))
GEOR - Heat and steam	C09K-008/592	heat* OR steam* OR vapor*
GEOR - MEOR (Microbial Enhanced Oil Recovery)	C09K-008/582	MEOR OR (microbi* EOR) OR (microbi* enhanced oil recovery) OR bacteria EOR)
GEOR - Polymers and macromolecular compounds	C09K-008/588, 60	polymer* OR (macromolecular compound*)
GEOR - Repressuring or Vacuum	E21B-043/18	vaccum* OR repressur*
GEOR - Surfactants	C09K-008/584	surfactant* OR (surface activ*) OR tensoactiv* OR ("surface active agent*")
GEOR – WAG (Water Alternating Gas, combinations with injected gas)	C09K-008/594	WAG OR ("water gas ingect*") OR (water-gas) OR ("water co2 inject*")
WT - Flocculation or precipitation of suspended impurities	C02F-001/52	flocculat* OR precipitat*
WT - Sludge treatment devices	C02F-011/00	sludge* treatment*
WT - Solid waste disposal	B09B-003/00	solid wast*
WT - Sorption	C02F-001/28	sorption*
WT - Water treatment	C02F-103/10 OR C02F-001/00	water treatment*
WT - Water treatment contaminated by oil	C02F-101/32	none
WT - Water-oil separation	B01D-017/032	none
WT- Flotation	C02F-001/24, 40	flotation*
WT- Water multistage treatment devices	C02F-009/02, 04, 14	none

AND

WIPO Environment domain IPCs	**IPC and Technology Concordance Table.** Schmoch, U. 2008. IPC and Technology Concordance Table. World Intellectual Property Organization. https://www.wipo.int/meetings/en/doc_details.jsp?doc_id=117672 (accessed 18 Jan. 2025).

Table S2. Total numbers and percentage distributions of EOR and environmental protection (EOR&Env) technological methods from 2004 to 2023 within BRICS and non-BRICS.

EOR&Env method	Patents (TRL4-5)			
	Counts		(%)	
	BRICS	nonBRICS	BRICS	nonBRICS
GEOR - (Polymers OR macrocompounds) and Surfactants	74	30	1.7	1.8
GEOR - Combustion in situ	164	124	3.8	7.5
GEOR - Fracturing, fracture reinforcement, interconnecting wells	51	36	1.2	2.2
GEOR - Heat and steam	610	331	14.2	20.0
GEOR - MEOR (Microbial Enhanced Oil Recovery)	27	16	0.6	1.0
GEOR - Polymers and macromolecular compounds	317	126	7.4	7.6
GEOR - Repressuring or Vacuum	59	51	1.4	3.1
GEOR - Surfactants	154	61	3.6	3.7
GEOR – WAG (Water Alternating Gas, combinations with injected gas)	19	25	0.4	1.5
WT - Flocculation or precipitation of suspended impurities	102	66	2.4	4.0
WT - Sludge treatment devices	327	37	7.6	2.2
WT - Solid waste disposal	195	68	4.5	4.1
WT - Sorption	81	67	1.9	4.0
WT - Water treatment	667	209	15.5	12.6
WT - Water treatment contaminated by oil	97	79	2.3	4.8
WT - Water-oil separation	51	36	1.2	2.2
WT- Flotation	737	271	17.2	16.4
WT- Water multistage treatment devices	564	23	13.1	1.4

Table S3: Compound annual growth rate (CAGR) of EOR and environmental protection (EOR&Env) technological methods for 2004–2023 and their temporal trends of patents, and patents normalized by 2023's output indicators: population (millions) and GDP (billions) for BRICS and non-BRICS.

CAGR (%)					
Indicator	**Dataset**	**(2004–2005 to 2010–2011)**	**(2010–2011 to 2016–2017)**	**(2016–2017 to 2022–2023)**	**Total 2004–2023**
Biannual patent average	BRICS	21.8	20.2	-4.1	12.0
	NonBRICS	8.9	-5.1	-25.1	8.2
Biannual patent average per million population	BRICS	20.5	19.0	-4.7	11.0
	NonBRICS	7.8	-6.0	-25.6	-9.0
Biannual patent average per trillion GDP	BRICS	13.0	14.0	-8.0	5.9
	NonBRICS	1.14	-10.0	-28.1	-13.2

Table S4. Temporal evolution of concentration (HH), specialization (CV), and diversification (DIV) across four biennia of EOR and environmental protection (EOR&Env) technological methods of BRICS and non-BRICS, for the biennia (2004-2005, 2010-2011, 2016-2017, and 2022-2023).

Indicator	**Dataset**	**2004-05**	**2010-11**	**2016-17**	**2022-23**	**2004-2023**
Specialization - CV	BRICS	174	175	157	207	153
	nonBRICS	189	167	150	238	180
Concentration - Herfindahl–Hirschman Index HH	BRICS	0.11	0.11	0.11	0.13	0.109
	nonBRICS	0.12	0.11	0.10	0.13	0.106
Diversification - DIV	BRICS	0.52	0.51	0.52	0.46	0.54
	nonBRICS	0.49	0.56	0.58	0.45	0.56

SUPPLEMENTARY MATERIAL

FIGURES

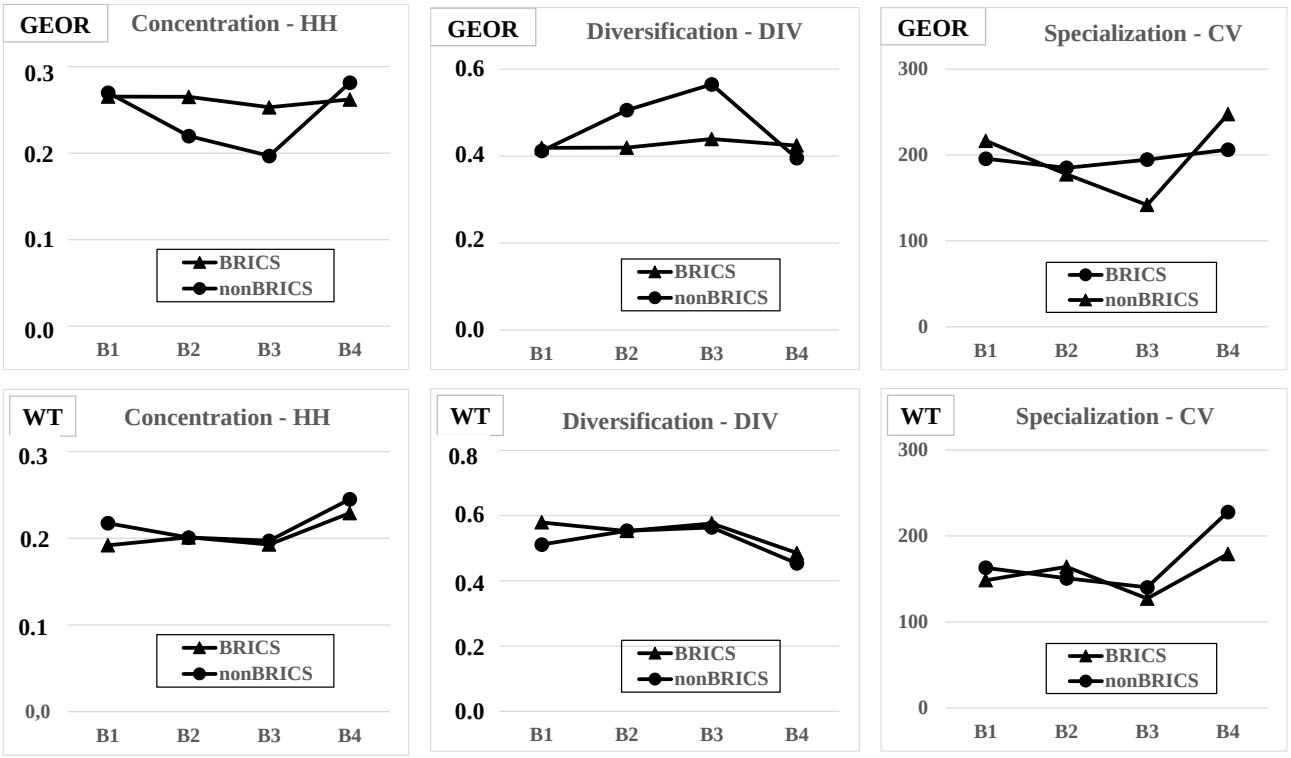
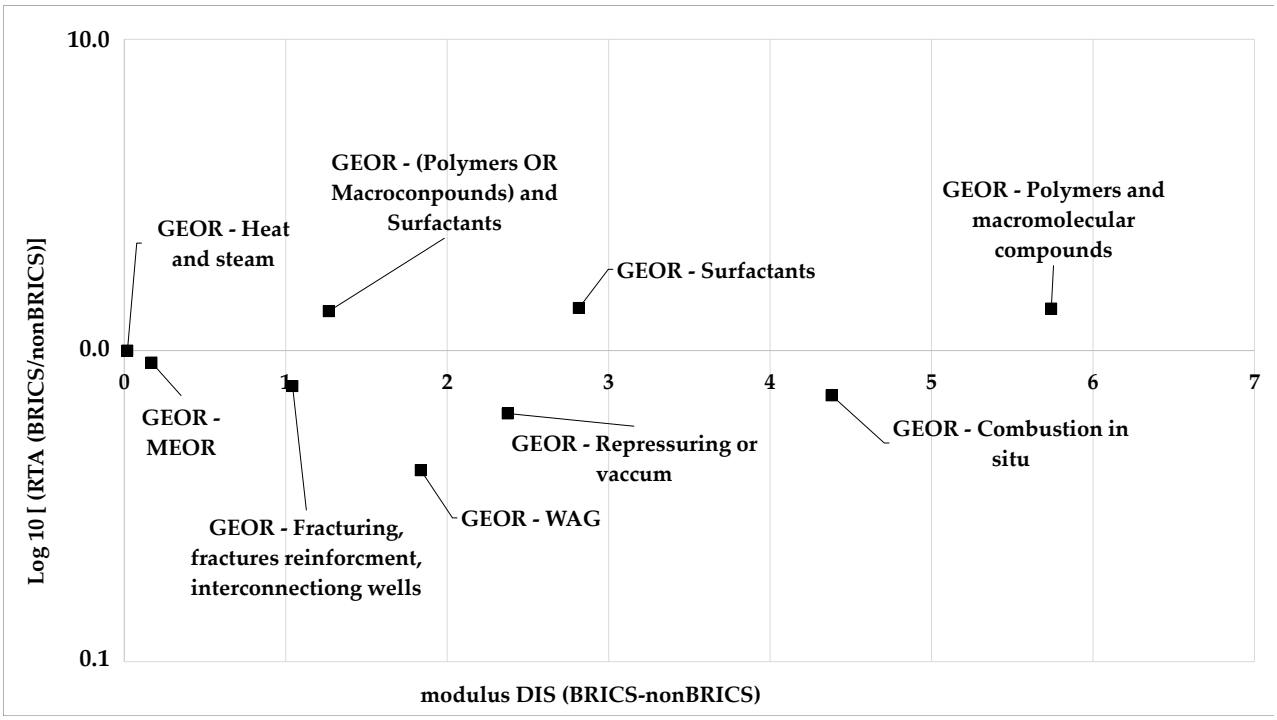


Figure S1: Temporal evolution of concentration (HH), diversification (DIV), and specialization (CV) of EOR&Env patents for BRICS and non-BRICS, across four biennia, for GEOR (top) and WT (bottom): 2004-05 (B1), 2010-2011 (B2), 2016-2017 (B3), and 2022-2023 (B4).

TOP



BOTTOM

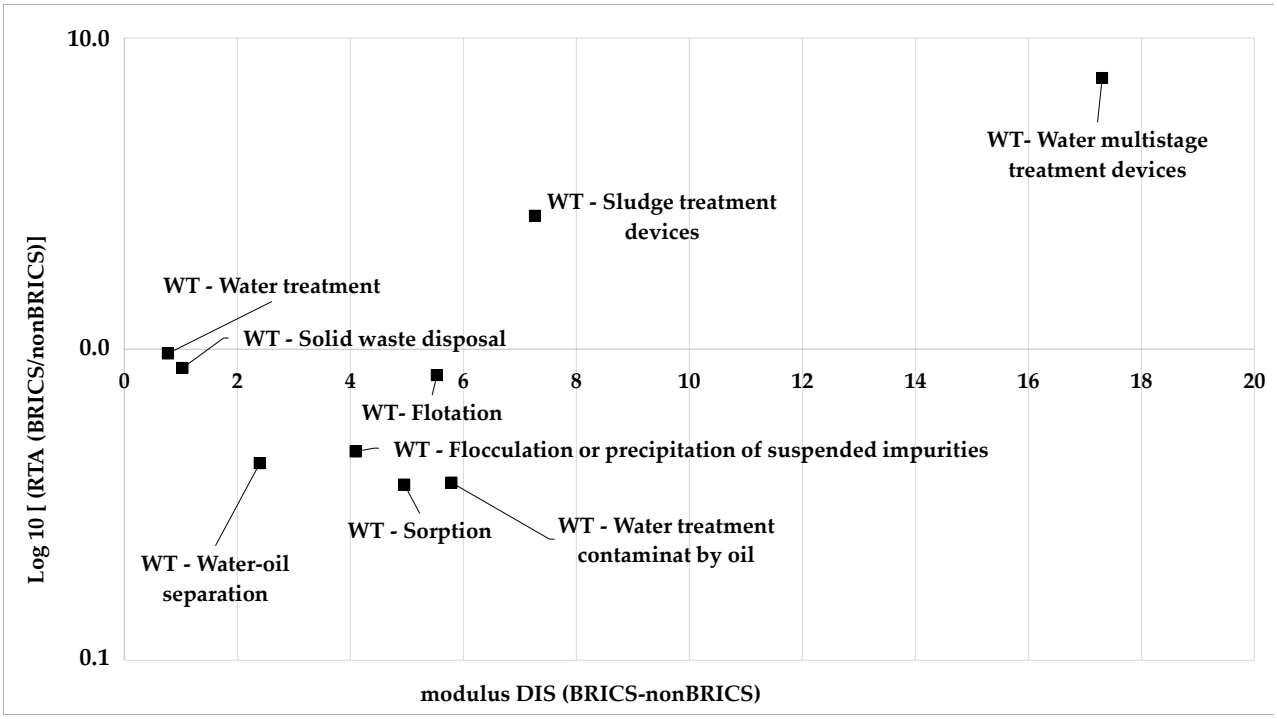


Figure S2. Relative positioning of GEOR (top) and WT (bottom) methods, displaying the logarithm of the Revealed Technological Advantage (RTA) as a function of Technological Distance (DIS) from 2004 to 2023, for a comparison between BRICS and non-BRICS.