STUDY REPORT

Deployment of innovative renewable energy technologies to 2030

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Abstract

The report summarises the findings of a study using semi-structured interviews with high-level experts and representatives of European renewable energy industry seeking their estimates of the scale, size and timing achievable for the introduction into EU and global markets of innovative renewable energy technologies ("i-RES" in the text that follows) compatible with the definition for such technologies in the European Parliament's amendment to Article 1 of the Renewable Energy Directive. The interviews were supported by quotable documentary evidence and supporting desktop research. The study has shown that industry is ready, in the right circumstances, to deploy i-RES to a level likely to exceed 5% of the REPowerEU target for 2030 of 45% renewable energy penetration in final energy demand. Advanced photovoltaics and floating offshore wind will make the largest contributions to 2030 whilst other innovative renewables together are likely to achieve contributions on a single digit GW scale.

Keywords: Renewable energy technologies, Innovation, Deployment, Gigawatts, RE Directive, 2030

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Overview of findings

In order to obtain a bottom-up picture of the EU renewable energy industry's readiness to bring out innovative renewable energy technologies by 2030, this thorough and wide-ranging interview study gathered the views and references of high-level representatives of industry, covering six categories: technology developers, project developers, EU supply-chain/OEMs (Original Equipment Manufacturers, investors/financiers, advisors/analysts and a small number of public administrators. In a series of semi-structured interviews during August and September 2022, respondents were asked to state their ambitions in respect to two specified time periods, 2023-26 and 2027-30. The questions and background note that were communicated to interviewees in advance are in annex.

The study has showed that the industry has sufficient ambition and plans for technologies that fall under the European Parliament's draft definition of "innovative renewable energy technology" (sometimes shortened to "i-RES" in the text that follows) to justify more than 5% of the overall goals of generation capacity from RES for 2030 given by the European Commission in the REPowerEU Communication COM (2022) 230, which called for 45% of final energy demand from renewables by that date. The study indicates the lion's share of innovative technology will be found in advanced photovoltaics and in floating offshore wind, but with credible ambitions (GW-scale) from other qualifying renewable energy technologies.

Advanced made-in-Europe PV a major contributor

For advanced PV alone, the main contributor identified in terms of GW, our assessment of the scale of ambitions is for 30 to 50 GW annual European manufacturing capacity by 2030, with more than 10 GW cumulative installed PV from this expanding capacity already by end 2026. This capacity is concentrated on the i-RES technologies of high-efficiency heterojunction cells and silicon/perovskite tandem cells. (Numbers given by developers were discounted somewhat based on our assessment of the interviews, allowing for some overlap caused by the different business models of the companies interviewed). This estimated expansion is well above 5% of the total EU 2030 PV target of 420 GW defined by REPowerEU, up from 165 GW by end 2021 [1]. That year, almost 26 GW was installed, and capacity additions in 2022 may reach 40 GW [2] . European PV module production capacity was 8.28 GW/year in 2021, not all of it used. Worldwide, PV module production in 2021 was about 190 GW, 93% of which in Asia (75% in mainland China). 160 GW used monocrystalline silicon wafers.

Floating wind to reach 10 GW by 2030, kicking-off major growth

In windpower, all interviewees see floating offshore technologies as the leading contender for i-RES. Estimates for industry-wide deployment by 2030 are 10 to 20 GW cumulative by most technology and project developers interviewed (our assessment, with some discounting of interviewees' claims) up from today's <0.2 GW.

For 2026, most individual developers' ambitions are less than a GW even when allowing for FID (Final Investment Decision) and not COD (Commercial Operation Date, i.e. entry into operation/first power) as the criterion for inclusion. A few of the companies interviewed are more bullish, especially for 2030, and one project developer has very much higher expectations. Ambitious new targets from a number of countries, some having been announced during the time of the interviews [3], may change this in the upward direction for both time frames considered.

Reported low estimates are mainly due to the long lead times characterising offshore wind projects and the time and effort needed for the scale-up of floating solutions from their current stage of pilot arrays, which are all less than 100 MW. Deployment is also held up by the perceived cost of most proposed floating technologies (substantially higher than those of seabed-fixed wind farms).

To put these numbers into context, the European Commission's overall target for wind power is 480 GW for 2030 [4], up from 189 GW by end 2021 of which 16 GW is offshore. Industry body Wind Europe expects 21.9 GW installed in 2022, projected to rise to 28 GW in 2026 in its "realistic expectations" scenario for Europe including the UK, Norway and Turkey [5].

Innovation in deployment and contributions from other sectors

In addition to innovation in PV based on new materials, innovation is to be found in the way PV is deployed, e.g. as **floating PV** or **agri-PV** ("agrivoltaics" – PV on farmland simultaneously used for crops). Some interviewees claim multi-GW potential for these applications in the EU by 2030. Globally, floating PV is already deployed at a scale of 3 GW, mostly in Asia, and some EU countries, e.g. Germany, are legislating for it. Floating PV is actually two different markets: **Inland lakes** (on hydropower reservoirs or flooded open-cast mines) have received the greatest attention so far, while

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[1] Fraunhofer ISE *Photovoltaics Report,* 22.09.2022, EurObserv'ER incl. decommissioning: 158GW; IEA-PVPS lists 178 GW.

[2] "Global market outlook for solar power 2022-2026", Solar Power Europe 2022.

[3] For example, Portugal has pledged to launch a tender for 10 GW of floating wind in 2023.

[4] REPowerEU, COM (2022) 230.

[5] "Wind Energy in Europe - 2021 Statistics and the outlook for 2022-2026" Wind Europe, March 2022.

offshore installation could enable scaling-up the size of plants without the restrictions on area use that can apply on land. For that, floating PV arrays must cost-efficiently resist the more challenging conditions at sea which include greater wave loads and the corrosive nature of seawater.

In the study, we interviewed an SME developer who reported useful learning from MW-scale floating PV pilots on reservoirs including in Europe, with multi-GW ambitions for 2030; a senior manager with a major supply-chain company who estimated up to 10 GW floating PV worldwide by 2030, but only on inland waters (up to half in Europe); and a top-3 European utility manager who, in contrast to the former, believes primarily in offshore floating PV due to its potential for building very large farms at sea.

Co-location, or even full integration, of offshore solar and wind power are cases of **"multi-use"** of the marine space, which maritime spatial planning rules must anticipate and facilitate, a desirable result of maritime spatial planning, and was mentioned by all three. Among EU Member States, Germany, Belgium and the Netherlands are exploring such opportunities with on-going pilot projects that could lead to multi-GW installations after 2030. The OEM-company manager also saw offshore multi-use beyond solar & wind energy, mentioning a potential for also non-energy uses such as desalination and aquaculture at GW-scale in Europe, from 2030.

The advantage of reduced land-use requirement also favours "agri-PV", the deployment of (mostly utility-scale) PV farms on land simultaneously used for crop-growing. Deployment of this has reached a similar scale to floating PV worldwide, and EU countries e.g., France are starting to follow.

Other technologies primarily for electricity production such as CSP (concentrating solar power), geothermal, bio-energy in line with sustainability guidelines, biogas for electricity and CHP (combined heat and power), and tidal & wave energy may, by our assessment and based on the interviews, jointly bring to market as much as single-digit GW installations by 2030. Developers have higher ambitions and the ocean energy sector is aligned with the ambition of the European Commission's Offshore Renewable Energy Strategy (adopted in 2020) for 1 GW of ocean energy deployment by 2030. For tidal stream and wave energy, currently operational capacity in Europe (including UK which has the largest resource for both) is 1.3% of this target with annual installations for both sub-sectors having peaked in 2015/16 [6].

Several of these technologies are "innovative" in the sense of the ITRE definition by virtue of their "making exploitable a largely untapped renewable energy resource". **CSP** is innovative in that the business case for the technology rests on storing high-temperature heat collected during the day to produce electricity also after dark, but it is perceived by markets to carry added technology risk and so far, each plant needs a design process considerably more complex than for the equivalent capacity of wind or PV power.

Geothermal is an established renewable energy sector with nearly 16 GW installed base for electricity production [7], and still greater for producing heat, with high potential for commercial growth in each. Importantly, geothermal is baseload-capable and capacity factors as high as 85% are often realised [8]. The US leads in production, while in Europe, Italy, Iceland and Turkey have from 0.75 to 1.75 GW running. Iceland and Tuscany region (birthplace of the technology) get 30% of their power from geothermal [9]. Italy's potential for geothermal is much greater than its 6 TWh/year of electricity produced (from 0.94 GW) today and has been put at 115 TWh from 13 GW in national planning [10].

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[6] Ocean Energy Europe: Key trends and statistics 2021, March 2022.

[7] Think Geo-Energy, 10 January 2022. https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2021-installed-power-generation-capacity-mwe/

[8] European Technology and Innovation Platform on Deep geothermal: Vision for Deep Geothermal, 2018.

[9] GEOENVI project, coordinated by EGEC (2018-2021), https://www.geoenvi.eu/about-us/

[10] "Elettricità da geotermia, in 382 Comuni italiani c'è un potenziale da 115 TWh/anno termici", Greenreport.it 08.07.2022

Interview results in our study confirm the potential for expansion of innovative geothermal energy, and that the EU supply chain is fully capable of taking on the challenge. It has potential for GW-sized contributions in Europe by 2030, such as by the use of **Organic Rankine Cycles** (ORC), which enable the exploitation of lower-temperature sources and eliminates geothermal fluid leakage [11], and **deep geothermal**, which could realise geothermal's potential in many more EU countries and regions: as an example, Slovakia has a geothermal potential of 5.5 GW that local developers and utilities are ready to develop [12].

For **biogas** and **biomethane**, the basic technologies are quite mature but innovations especially in upgrading and processing the biomethane into a fully natural-gas-grid compatible-product is innovative and could be critical for its wider use e.g. as a source of industrial heat.

Airborne wind (electricity-generating kites or drones) is a proposed new set of technologies of some promise as it permits using high-altitude wind resources and has an entirely different value-chain structure from traditional wind power that potentially could be cheaper. Both onshore and offshore deployment has been proposed. While no independent assessment for EU conditions was available for the present study, a recent US assessment [13] considered the technology to have potential on a 10-year time horizon and sketched a structured plan to advance it towards markets.

In addition to airborne wind, there are other promising new innovative renewable technologies that could, with appropriate measures, be pushed through advancing Technology Readiness Level (TRL) if their advantages, once mature, could make GW-scale contributions to EU energy markets possible.

Contributions to electricity and heating

In sum, the **renewable electricity** sector seems capable and credible in its ambitions of justifying not just 5%, but to the order of 7% i-RES by 2030, corresponding to between 60 and 80 GW cumulative installed power generation capacity. There is a sizable upside potential, in that the adoption and acceptance by financiers may be swifter if, as these technologies mature further, they prove to be even more cost-efficient than expected. This would result in a rapid take-off on (then anticipated) market terms from the early 2030s.

In **renewable heat**, there is substantial potential for replacing natural gas by solar heat in homes, offices and commercial buildings, and in district-heating. Developers of innovative solar heat (both advanced flat-plate and concentrating) technologies have GW-scale ambitions for 2030.

Compared to electricity, it is harder to make robust quantitative estimates for GWs of i-RES for heat due to the heterogeneous and dispersed nature of heat demand and above all the local character of the heat markets. We estimate that innovative applications combining solar heat with use of heat pumps and heat storage could result in the replacement of several hundred TWh/year of heat today generated by fossil fuels, meaning that the share for i- RES technologies used for heating would correspond to more than 5% of the estimated new total generation capacity needed [14]. Assuming appropriate market measures, and based on information from our interviews, we estimate that solar heat could fulfil up to 20% of 2030 EU-27 heat demand, which is estimated at 1800 TWh in an August 2022

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[11] "Thermal energy harvesting", Knowledge Center on ORC, published 04.02.2022, www.kcorc.org/en/committees/thermal-energy-harvesting-advocacy-group/

[12] "Slovakian geothermal demo gains pace", Renewables Now, 16 May 2022.

[13] J. Weber et al. Airborne Wind Energy. Report NREL/TP-5000-79992. https://www.nrel.gov/docs/fy21osti/79992.pdf

[14] The exact calculation is beyond the scope of this report, as it is complicated by the lower relative role of heat in primary energy demand that characterises the strong increase in electrification common to all scenarios modelling the EU energy system to 2030 and beyond.

study by TU Wien and EREF [15]. Industries needing heat up to 120 °C or low-pressure steam, which include food and drink, agro-processing and paper, could be effectively served by solar heat even in mid- and northern EU latitudes, if market conditions are adapted and some geographical/temporal mismatch is eliminated by use of available heat-storage and heat-pump technologies.

For higher-temperature heat (above 160°C), which makes up a substantial part of the heat demand in highly industrialised EU regions (Germany's Ruhrgebiet, North Italy…), we find the most credible path to replace fossil sources seems to be through gradual replacement of natural gas in the grid by highly refined biogas, i.e. biomethane, which can be freely admixed in the existing natural gas infrastructure on a local or regional basis. Electricity may also be used directly for high-temperature heat, notably in some otherwise difficult-to-serve industrial applications. Renewables could serve higher temperature heat demand better if cost-effective heat storage for temperatures of at least 400 °C could be brought to market, according to an interviewee developing this technology.

(Note on scope: Hydrogen and RFNBOs were not considered in this study, and non-hydrogen energy storage is covered only in relation to integration of renewable heat, as illustrated by the case above. This is to align with the European Parliament's amendment, which relates only to "generation technologies").

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[15] Study on 2030 renewable energy and energy efficiency targets in the European Union, *TU Wien and European Renewable Energies Federation, 26 Aug 2022*

Interview results for estimated GW of i-RES technologies deployed to 2030

A table on the following two facing pages summarises the numerical answers given by interviewees, sometimes accompanied by short remarks and clarifications. The table lists (left page):

- Reference code for each interview (interviewees responded under strict confidentiality)
- Which technology interviewee considered to fall under the i-RES definition (answer to Q1)
- Category of organisation the interviewee represents
- Interviewee level: C = CEO/CTO or equiv., 1 = top manager, 2 = senior manager/specialist
- Precisions regarding the technology or interviewee
- ”Own” <u>installed</u> GW in the two periods 2023-2026 and 2027-2030; for the company or under the organisation’s responsibility; low to high range if an exact number was not given (Q3)
- “Own” manufacturing capacity (for PV) in GW/year by end 2026 and by end 2030

(second, facing page):

- Total installed generation capacity industry-wide for the two periods (Q5)
- Whether interviewee thought i-RES status should apply equally for both time intervals (Q6)
- Any specific countries or group or countries for the numbers estimated (Q4)
- Assumptions quoted by interviewee (Q2/3) or remarks on the responses given
- Reference code again to facilitate reading the facing pages table.

Some statistics on the interviewees is given by Figures 1a and 1b :

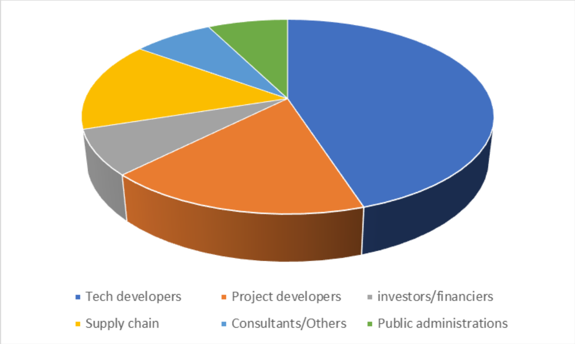

Fig. 1a: Interviewees by organisation type

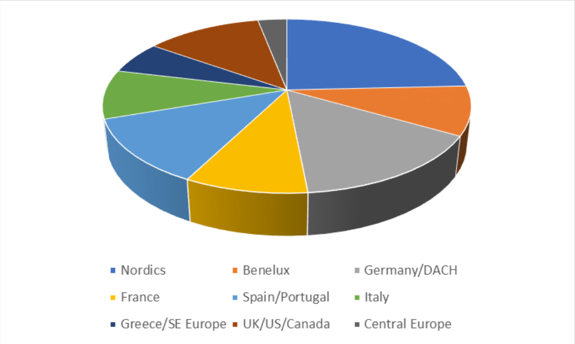

Fig. 1b: interviewees by country of activity.

The emphasis on technology developers was intentional. There is some double counting in terms of company type as a few respondents (and their companies) can be assigned to more than one group.

84% of interviewees were of top or high experience and authority within their companies, with the remainder being employed as senior specialists in their field. As is unfortunately still typical for the energy industry, few women were among the interviewees, but those women interviewed without exception held very high positions.

Table: Interview estimated GW for i-RES technologies assessed

interview code	Q1: which technology	type of organisation	int'wee level	precisions	Own installs, 2023-26			Own installs, 2027-30			Mfg cap by 2026 GW/a est.			Mfg cap by 2030 GW/a est.		
					low	est	high	low	est	high						
001	PV tandem cells	tech developer	1	Si/perovskite		5			10			2			5	
002	PV tandem cells	tech developer	C	Si/perovskite		10			25			5			25	
003	All HJT PV	tech developer	1, 2	premium segment								7			10	
004	HJT + maybe Si/Pe tander	tech developer	C	premium segment								3		12		15
005	advanced PV	component/value chain	C	new materials dev.							5		6	25		30
006	Advanced materials PV	early stage investor	1	early investor view							5		10	20		40
007	PV floating, inland waters	energy industry OEM	1	inland waters only												
008	Floating PV	tech developer	C	inland waters		0.5			2.5							
009	PV offshore	project developer/utility	1	offshore only		0.2			1							
010	PV/thermal hybrid	tech developer	1	rooftop, buildings								0.06			0.25	
011	CSP	association (ex utility)	1	electricity only												
012	Solar heat	tech developer	1	hi-vac flat panels		0.25			5.5						1.7	
013	Solar heat	tech developer	C	hi-eff parab. troughs		0.1		1		10						
014	Solar heat	tech developer	C	Fresnel-lens tracked		0.2			2.5							
015	High temp. heat storage	tech developer	C	steel electr. heated		1			2							
016	Deep/advanced geotherm	component/supply-chain	1	electricity + heat												
017	Advanced bioenergy	component/supply-chain	1	electricity + heat												
018	Bioenergy incl. CHP	public admin (int)	1	broad estimate												
019	Pyrolisis-derived liquid fue	tech developer	1	tech director		0.2			2							
020	Large heat pumps	component/supply-chain	1	ORC cycle based												
021	Other i-RES HP's	supply chain/component	1	i-RES sector view												
022	Wind on- & offshore	project developer/utility	1	FID basis	0.1	0.2	0.4	0.8	1	1.5						
023	Wind offshore	public admin (MS nat auth.)	C	Artifical islands												
024	Floating wind	early investor	1	early investor view												
025	Floating wind	tech developer	C	claimed cost leader		0.5			1.9							
026	Floating wind	tech & project developer	1	worldwide rentals		0.5			5							
027	Floating wind	tech & project developer	C	is a former CEO		0.138		2		3						
028	Floating wind	project developer/EPC	1	pure play EPCI dev		0.4			1							
029	Floating wind	project developer	2	pure play proj dev		0.1			1							
030	Floating wind	industry advisor	C	promotor												
031	Offshore wind	public admin (MS)	2	former role												
032	Offshore wind	project developer	1, 2	floating + some fixed		2			3							
033	Offshore wind	industry advisor	1, 2	mainly floating												
034	Wind on & offshore	energy industry OEM	1	all FOW is i-RES												
035	Floating wind	tech developer	C	also turbine OEM		0.2			4.5							
036	Multi-use offshore wind			fixed or floating												
037	Tidal & wave	early stage investor	1	early investor view												
038	Tidal	tech developer	C	developer view		0.1			0.5							
039	Onshore wind off-grid	energy industry OEM	1	wind for Hy export		0.2			2							
040	3-d printed WT blades	energy industry OEM	1	& other additive mfg								1			5	

Total installs, 2023-26			Total installs, 2027-30			Q6	Q4: countries	Q2/Q3: assumptions, remarks...	ref code
low	est	high	low	est	high				
						yes		new 2GW/yr fab 2024, next ones 2027-30, 18-24 mo constr. time, Eur suppliers/value-chain critical	001
	10			65		yes	50/50 Eur/NA+As	sell turnkey plants/lines, outsource equipm mfg: note double-counting & time-shifted	002
						yes		in process of updating 2030 targets. This is for all HJTand doesn't assume perovskites	003
						yes			004
8		10	42		52	yes		numbers in red refer to all mfg cap p.a., not just "own"	005
						yes		10GW/yr mfg cap is 25% of total (2026), rooftop & utility each 50%	006
1		2	5		10	yes		EU inland waters only. local authority permitting critical.	007
								main mkts SE Asia but EU coming. 5GTW pipeline. Demo plant in Europe (Albania) restarted	008
	0.2		2		4	yes		why offshore? Because can make PV fields very large.	009
						yes		assuming markets for hybrid panels will open...	010
	0.2		1		2	yes	GW in EU	Spain dedicated auction, also PT and IT, MENA could be several GW	011
						yes	DE, FR	company ramp-up plan, mfg cap >2GW/a from 2030	012
						yes		no tech reason can't install 100's TWh by combining technologies	013
						yes		barriers are regulatory & financial, integration of technologies...	014
						yes		enabling tech., claims credible, utility support; market adoption need to be proven	015
	0.2			1		yes	mostly IT, TR	is for "continental europe" i.e. excluding IS: IT capacity doubled	016
	0.5			2		not sure		for i-RES not only ORC and depend critically on future bioenergy sustainability criteria	017
	1			5		yes but		depends on evolving sustainability criteria, EU only part of these numbers	018
	0.5		2		5	yes		logistics and regional/distributed processing of biomass is main barrier	019
	1			5		yes		critical for integrated solutions for heat; distributed bio-CHP continuing	020
2		5	5		10	not sure		Low est., uncertain on i-RES share and Euro industry & value chains role	021
4		5	10		12	yes		2020s only 100-400MW farms, Europe est 1.5GW (2026), 2.5GW (2030) is "a bit aggressive"	022
	0			3.5		yes		several MS planning and Belgium has approved plan for COD of 3.5GW by 2030	023
1		2	7		15	yes		"expecting UK and NO to lead, EU countries especially Southern ones to follow"	024
	5		10		15	yes		own plans to 2028 (COD in 1st period, FID in 2nd), further depends on investor (Energy Major)	025
						yes		specific biz mod: renting to O&G operators	026
						yes		pipeline outside EU much bigger; e.g. Korea	027
	5			20		yes		of 20GW in 2030, 15 will be in Eur (UK+FR, maybe NO, IT)	028
2		4	10		20	yes	SE, UK,NO	Some markets underrated e.g. SE	029
	10			20		yes	mostly Asia	Eur markets: UK, FR, NO; US is the long term big target	030
1		2	3		5	yes		is for one large Member State only; political/regulatory risks large	031
	37			72		partly	10 of 37 in Eur	concern that reserved 5% segment status may scare off mainstream investors	032
	2			11		yes		11 GW by 2030, 10 in Eur; 94GW by 2040 (Asia lead), 158GW by 2050 (NoAm lead)	033
1		2		10		yes		FR, ES/PT, IT, possibly IE and EL main EU countries for floating	034
						yes		incl WT sold for non-floating use	035
	0.2			3		yes		MU = desal, aquaculture; maritime space sharing.	036
	0.1			0.2		yes		believes UK will dominate markets till after 2030	037
	0.2			1		yes		Can do 1GW 2030 claimed cost leader. IE is promising EU27 market, possibly France	038
	1			5		yes	CL, AR, AU	overseas countries with large area, Hy sales to EU but also US, JP	039
						yes		10MW WTs, 100 rotors/GW, key to keeping WT mfg in Europe	040

Summary comments on main i-RES technologies

Advanced photovoltaics

In the **advanced photovoltaics** market, where the aim of the game is higher efficiency, five European manufacturers (of cells, modules and components) were interviewed at high or highest level. One early-stage investor included advanced PV in a broader portfolio of technologies in which they invest. **All considered that advanced heterojunction and tandem PV modules of all materials categories should be categorised as i-RES and they all considered these to fall under this classification for both time brackets 2023-26 and 2027-30.**

The PV technology developers were split on their estimates of the near- and medium-term future specifically for Si/perovskite tandem cells. Two companies stated that they are already commercialising such products, with major investments in manufacturing plant on-going. Both gave multi-GW manufacturing capacity estimates for 2026 and still greater for 2030. (Note: these two use different business models, partly overlapping, so the numbers in the preceding table include some double counting). One European PV manufacturer, which has announced the building of GW-scale manufacturing of next-generation heterojunction cells with interdigitated back contacts ("IBC cells"), expressed some reservations about the maturity of Si/perovskite tandems, citing both technical and market concerns. Another company, which is developing new materials for future solar PV systems, ascribed its scepticism on Si/perovskite cells to concerns about their durability [16]. The fourth manufacturer, currently building a 3-GW facility for heterojunction bifacial cells, is keeping the option open of transitioning some or all of their fab to Si/perovskite tandem cells: although the funding of their plant was made independently of this technology's maturity, they are designing in a Si/perovskite pilot production line capability to their fab. The representative said that adoption of Si/perovskite tandems could boost manufacturing capacity by 10% in GW terms due to their higher efficiency.

Independently of their views on Si/perovskite tandems, the interviewed companies' estimates of their own annual manufacturing capacity range from 2 to 7 GW/year by end of 2026, ramping up to between 5 and 25 GW/year by end 2030. Each company is targeting the "premium" market segment, although with a slightly different understanding of the term.

Estimates for total (cumulative) installations were 10 to 15 GW by 2026 and between 42 and 65 GW by end 2030. The 2026 figures are uncertain due to the ramp-up being step-wise, with each new fab adding at least 2 GW capacity. Not all company interviewees wished to give industry-wide estimates, but the figures for cumulative installs are broadly consistent with the manufacturers' statement of their own manufacturing ambitions. Similarly, companies did not wish to be interpreted on their own aimed-at market shares; however, it is clear that the foreseen share of the four PV manufacturers together is substantial (10 to >20% of the global premium market), which indicates that as a whole, the interviewees selected are highly relevant in the context of the various ongoing initiatives aimed at re-shoring and expanding EU PV manufacturing.

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[16] This is well known in specialist literature. One technology developer who favoured Pe/Si tandems considered that their manufacturing solution, currently being invested in for ramp-up, had solved the durability problem for their tandem cells, but declined to give details on the exact nature of their proprietary solution – obviously, there are important IP aspects here.

All the industry companies interviewed pointed out that the advanced position of EU research and technology, as illustrated in Fig. 2, is a big strategic advantage but to be competitive and maintain this position, the presence of a full supply chain in Europe is necessary.

Fig. 2. EU research lab where leading-edge techniques for manufacturing silicon heterojunction cells such as those addressed by i-RES technologies for PV are being developed. *Source:* Fraunhofer ISE.

As for barriers, interviewees highlighted the substantial scale of new facilities, typically 2 GW per fab, and the long time (typically 18 - 24 months) to get new capacity up and running once permitted.

The early investor executive gave an estimate of annual manufacturing capacity that was relatively in line with those of manufacturers, for both the 2026- and 2030-time frames. He was optimistic on Si/perovskite tandems and felt that half of such modules would be deployed in the rooftop/building-integrated market, and half in utility-scale installations. Manufacturers were most focused on serving the ground-mounted market; however, there are reasons for both markets to attract high-efficiency products: for buildings, because of a wish among building owners to maximise production on limited roof areas; for ground-mounted systems, because these are bought by utilities who should be willing to pay more upfront for a product that will generate at a lower levelised cost of electricity once its productivity and lifetime are taken into consideration.

Comments on **floating PV** were made on pages 3-4. The expected contribution of this new innovative application case is of several GW by 2030, although by that date more is likely to be installed outside the EU than inside (despite Germany alone, according to a 2020 study, having a theoretical potential of 56 GW on lakes from former mining activities [17]). European developers have a strong position in the high-growth markets such as South East Asia[18], the know-how from which will help take-up of the technology in their home markets.

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[17] https://eurec.be/fraunhofer-ise-analyzes-potential-of-solar-power-plants-located-on-pit-lakes-in-former-lignite-mines/

[18] The Singapore government has announced 60 MW on a reservoir.

Other solar electricity

Two senior experts in **concentrated solar power** (CSP) were interviewed and shared their ambition for 1 to 2 GW of new installed capacity by 2030. 2.3 GW is installed in world-leader Spain, which has a target of 5 GW by 2030. Portugal, Italy, and MENA countries are also prime candidates for further installations. The success of large “first-of-a-kind” plants designed to prove technology innovations is important for the return to growth of CSP electricity, and an upcoming Spanish national auction [19] is expected to be decisive by offering ring-fenced funding for 0.22 GW of new CSP. As regards barriers, interviewees cited insufficient market conditions, such as auction designs failing to take account the “system value” of CSP with heat storage to provide power during the evening peak as well as long permitting and construction times.

One EU manufacturer of **hybrid PV/thermal** solar collectors was interviewed. The lead market for their product, a high-efficiency thermal collector integrated with an adapted PV module, is on large buildings (e.g., hotel chains, hospitals) with significant sanitary hot water needs, as it allows better use of limited rooftop space than separate installations of PV and thermal. The company is designing a manufacturing line that can be scaled up to 0.25 GW/year. However, it is currently held back by low market demand.

Renewable heat (solar heat, heat pumps and heat storage)

Europe’s installations of **solar thermal** collectors stood at 37.5 GW_{th} at the end of 2020, producing 26.8 TWh heat per year. This was less than half the EU target for that year of 78 TWh. Worldwide, the IEA Solar Heating & Cooling programme reported an installed power of 522 GW_{th} producing 425 TWh of heat [20]. China counts for more than 70% of solar heat production. In 2016, in EU-28, solar heat covered 0.65% of overall heat demand, not counting solar supply to district heating [21]. Germany, Greece, Italy and Spain are the largest EU markets with 60% of the total. Annual growth has been less than 2% in the last few years (leading to a “lost decade” in the words of some).

However, our interviews of three innovative solar heat technology developers in three European countries suggest the sector is reviving. One is a privately held manufacturer of high-vacuum flat-plate collector systems, another a listed company that produces solar concentrating systems using highest-efficiency small parabolic troughs, and a third makes dual-tracking solar collectors incorporating a Fresnel lens. All are SMEs with limited resources, quoting the dispersed nature of the heat market, with different rules in different places, as a significant barrier. Each is initially targeting the supply to district heating networks, which is a somewhat less fragmented market – however, their technologies are also capable of supplying to industrial processes at temperatures up to 140 (one claimed 160) °C. They observe that industrial heat customers are used to simply buying fossil gas for their heat needs, and even with expensive gas, customers show little appreciation of the need to adopt the “systems thinking” necessary for an effective and competitive solar thermal installation.

To help make their offer more attractive, all three developers are working on integrating their technology with various types of heat storage. One example of such is shown in Figure 3 below.

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[19] https://renewablesnow.com/news/spain-to-award-520-mw-of-renewables-in-oct-25-auction-792371/

[20] IEA SHC 2022 quoting data at end 2020

[21] Project “Heat Roadmap Europe” , Grant Agreement 695989, 2016-19

The first company has the objective of installing 0.25 GW of solar collectors by 2026 then 5.5 GW by 2030, by which time it aims to be capable of manufacturing 1.7 GW/year.

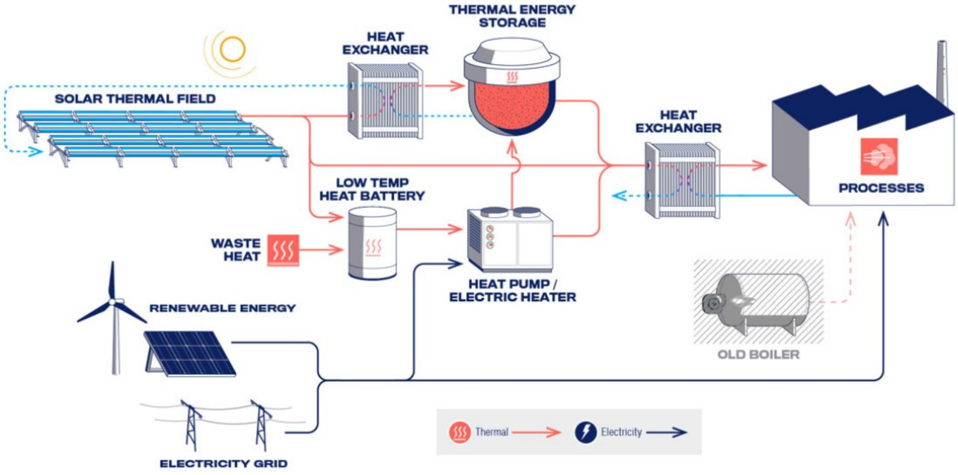

Fig. 3. Integrated solar heat system for industrial processes. *(Credit: FRIENDSHIP project [22])*

The second company operates a fully automated manufacturing line of capacity 0.1 GW/year and is active in numerous European projects and networks. Its target is to multiply this capacity by 2030. The third company operates a MW-scale pilot installation, has similar ambitions to scale up and is additionally working on a novel concept for storing heat in rocks.

An opinion shared by all three is that the deployment of their technologies at a scale of 100s of TWh by 2030 presents no real technical challenges. They intend to draw on the innovative integration of their efficient solar collectors with appropriate **heat-storage** solutions and, for some applications, add high-capacity **industrial heat pumps** to upgrade the heat to temperatures needed for a specific industrial process. As to large-scale heat storage of a few months, one company points to the example of Denmark, which has built 160 pit storages for heat at up to 90 °C, most of which are connected to district-heating networks.

A world-first demonstration of the industrial use of heat from parabolic reflectors in the Port of Antwerp (Belgium) produces steam for the cleaning of freight containers and tanks, which used to need gas-fired heat to obtain desired steam pressure and quality.

One company interviewed has deployed its Fresnel-lens solar collector field, another world first, on the Danish island of Møn at 54.7 °North. Its low-cost materials currently allow up to 100 °C operation, which is sufficient for district heating, and the company wants to reach higher temperatures to supply industrial process heat.

Box 1 Two recent examples of solar thermal projects delivering heat at 100°C or above at mid-EU latitudes

Pit storages can be GWh-scale and may be combined with high-capacity heat pumps to deliver heat at higher

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[22] Project funded under Horizon 2020 with Grant Agreement 884213, on-going 2020-24, https://friendship-project.eu/

temperature. The technologies are mature and their integration presents mostly practical challenges rather than major technology or scale-up risks.

Each 100 TWh of solar heat at up to as much as 200 °C (relevant to the **process heat** demand of the agri-food industries mentioned above) would need c. 100 GW_{th} solar input using concentrating technologies at mid-EU latitudes (1000 hours DNI /year), or as little as 80 GW_{th} in southern European countries where 1200-1250 hours DNI /year are found (Box 1).

In addition to the **barrier** of fragmented markets for heat, the interviewed solar heat developers point out that access to capital for large investment projects is a limitation because their offerings are seen as more complex and riskier than correspondingly mature electricity applications.

REPowerEU calls for “30 million new **heat pumps** by 2030”, a substantial increase on the 17 million installed by end 2021 equating to nearly 130 GW_{th} [23]. In residential and tertiary sectors, lead markets have traditionally been countries where electrical heating is widespread, e.g. France or Norway, but this is changing as the need for increased total capacity and gas substitution drives expansion of the large industrial heat pumps (several MW) segment. EU manufacturers and supply chains have ambitions to address these growth markets, and bring out products that may be compatible with the definition for i-RES in several Member States. It appears from our study that a good way to maximise impact of the REPowerEU target on heat pumps industrial applications is to establish a comprehensive “systems approach” to heat supply and heat markets in order to reduce their fragmentation. This includes the buildings sector, regulatory improvements and facilitating new innovative and demand-optimised efficient ways of addressing these challenging markets.

High-temperature industrial heat from biogas and pyrolysis liquids

An EU developer of innovative liquid fuels from fast pyrolysis of sustainably-sourced biomass was interviewed. This technology yields liquids or gases that can directly substitute their fossil fuel equivalents in existing heat or combined heat & power equipment. This is important for industry as few other fuels are available to supply high-temperature heat that are fully renewable and that can be produced in industrial quantities. The technology of fast-pyrolysis liquid fuels has reached a high level of maturity, and the developer is confident it can reach GW-scale by 2030. Organising the logistics around collection and processing of biomass, e.g. straw, which is then (pre-) processed in distributed plants, is complicated and can be a barrier to deployment. But an EU region having appropriate resources could scale up his technology quickly.

Assessments for **biogas** and **biomethane** were made based on literature. The REPowerEU strategy calls for a near doubling of biomethane production from 18 to 35 Bn m^3/year. While this would still be less than 10% of 2020 natural gas consumption, the sector is ready for expansion. The versatility of biomethane and readiness of hydrocarbon-processing industries to invest in it offers immediate benefits. There is substantial work to be done in upgrading biogas to grid-compatible biomethane. Counting upgrading facilities as i-RES, which is justifiable, would deliver a multiple-GW contribution to the target from biomethane by 2030. Germany is both the EU's leading producer of biomethane (10 TWh in 2018), and has its greatest industrial heat demand. To address this obvious opportunity,

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[23] https://www.ehpa.org/policy/accelerator/ and Th. Nowak, “European heat pump market”, *REHVA Journal* issue 04/2021, Federation of European Heating, Ventilation and Air Conditioning Associations, Brussels.

the significant regulatory barriers to biomethane development must be addressed including the persistent prioritisation of biogas for electricity production [24].

Offshore wind

In the wind power sector, interviews were carried out with wind-turbine developers, technology developers, project developers (ranging from independent promoters to Top-10 utilities), financiers and independent industry contributors, i.e. certification bodies and consultants. All noted that for seabed-fixed offshore wind, spectacular cost reductions have been achieved since 2015/16, whose strategic impact can be compared only to the falls in the cost of PV in the years before. Cost reduction has driven huge flows of private capital to the industry, which is likely to continue improving state-of- the-art technologies. The emerging trend to construct **artificial islands** as bases for construction and operation & maintenance (O&M) was mentioned as innovative, and Belgium has in place plans for 3.5 GW capacity addition already by 2030 using an artificial island as the cornerstone of its expansion [25], with Denmark, The Netherlands and other countries set to follow.

Further, interviewees agreed that **floating offshore wind** is the main contender for i-RES status in the years to 2030 and beyond. This technology opens up offshore wind development to countries that do not border shallow seas, like France, other Mediterranean countries, and Portugal. Even countries that do have shallow seas could use floating solutions to tap the stronger and steadier winds further offshore. Floating turbines can come with the bonus of being invisible from land.

Respondents typically give relatively high estimates (10 GW or more) for industry-wide cumulative installed capacities by 2030. This is a sign that they expect many others to be involved. With one exception (a company ranked in the top 10 European offshore wind project developers), respondents anticipate the greatest expansion of the floating wind segment between 2030 and 2050. This is due to the long lead times typical for such projects owing to their logistical, technical and regulatory complexity. As for contractual challenges, we found no consensus view of interviewees on the role of EPC (I) (Engineering, Procurement, Construction (+Installation)) contracting in accelerating growth, but the increased involvement of oil & gas operators in floating wind specifically is a major driver for this type of contracting, which is common in large hydrocarbon projects and often credited for influencing supply-chain innovation. One developer interviewed has partnered with an established oil & gas EPCI contractor, and another has ambitions to become one, drawing on experience within the wider company it is a part of.

The majority of developers are counting on mostly pre-commercial or early commercial floating wind farms or arrays of typically 0.1 to 0.3 GW being constructed or reaching FID in the years to 2030. Several are planning multiple projects in different countries, however, so these numbers are consistent with estimates by a leading certification body of 10 to 12 GW floating wind deployed by 2030, most of it in European waters. All developers agree that growth will accelerate strongly from 2030, with the interviewed certification body estimating 94 GW more by 2040 and 158 GW added by 2050. A consultancy has published higher 2030 targets of 15-16 GW [26], as has IRENA [27]. However, industry

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[24] REGATRACE project, Mapping the state of play of renewable gases in Europe, D6.1. 04.02.2020. www.regatrace.eu

[25] https://www.elia.be/en/news/press-releases/2022/10/20221003_offshore-energy-island

[26] Westwood Global Energy Group 21.06.2022 and recently at *RECharge Energy Transition Forum*, London 06.10.2022.

[27] IRENA *World Energy Transitions Outlook* March 2022.

interviewees quote barriers like the availability of offshore grid connections as a bottleneck, especially for deep-water windfarms that are far from shore (100 km or more), where the use of HVDC instead of conventional AC transmission infrastructure is advantageous but challenging to implement. Developments of the needed hardware are ongoing but according to recent industry forums [28] not currently on track for massive deployment before 2030.

For new offshore wind capacity coming on stream until 2030, major utilities assume (as of Q2/2022) that between 97 GW (Ørsted[*]) and 109 GW (Vattenfall[*]) of new offshore wind power generation will be installed in European waters, so the 10 to 12 GW estimate for floating shared by the majority of interviewees represents roughly 10% of the total to 2030.

Some floating technology developers interviewed detect an absence in the market of turbines that take fully into account the specific characteristics of floating installations. Turbine manufacturers don't deny this, but respond that they must focus on selling turbines in volume to be certain to make a profit, and the floating market is a lower priority for now because it is smaller, may require more customisation (depending on floater design) and is perceived to be more uncertain. Also, floating wind farms need reliable dynamic cables, which cable OEMs are still not prioritising sufficiently.

As for further barriers, some interviewees point out seabed risks, noting that even shallow seas like the North Sea (where >95% of offshore wind so far has been built) may have different metocean or seabed conditions that influence wind farm construction (e.g. anchoring). A minority of respondents express concerns for the availability of construction steel and mooring chain materials. This minority points to using concrete floaters instead, while proponents of steel designs note that even concrete floaters use sizable quantities of steel reinforcement bars. Figure 4 below shows two designs where the amount of materials needed has been made publicly available (for 11 MW-rated platforms).

Fig. 4. Comparison of steel and concrete floating wind power platforms, each rated 11 MW. Left, the OOFloat™, which uses 16 000 tonnes concrete, but also >2000 tonnes of steel rebars plus more steel in other parts [29]. Right, W2Power™ using c.3000 tonnes construction steel in its floater [30]. (Both cases exclude steel in towers, turbine nacelles and moorings. Illustrations are roughly to scale, noting that W2Power achieves its rated power capacity by using a pair of somewhat smaller 5.5 MW turbines).

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[28] 3rd Annual Conference Offshore Wind Transmission Europe, 14-15 Sept. 2022 Brussels (this author was a moderator)

[*] Not interviewed, however two of their peers in the Top 10 offshore wind project developers were. The numbers cited are taken from these two companies' Q2 2022 investor update call presentations.

[29] https://cordis.europa.eu/project/id/952979/results. OOFloat was recently sold by Dr. Techn. Olav OlsenAS to Boygues.

[30] https://www.innovationnewsnetwork.com/w2power-offshore-wind-deployment-worldwide/25183/

Whether concrete or steel, **material needs** are large for the envisaged expansion of windpower. As a further illustration, the mass of marine construction steel in the recently incapacitated NordStream 1 and 2 pipelines was around 2.2 million tonnes each. Even before REPowerEU, the wind power sector until 2030 was expected by industry to use at least three to five times that mass of steel – per year [31]. Estimates in Figure 5, dating from before REPowerEU's new higher target for EU wind capacity of 480 GW, are for onshore wind to consume around 10 million tonnes/year by the end of this decade and offshore more than 6 million tonnes/year.

Offshore wind is capital-intensive, with the world's largest offshore wind farm, Dogger Bank (3.6 GW) needing €10 Bn of capital expenditure. For the envisaged expansion to 480 GW wind power, which must include both onshore, fixed offshore and floating, the capital needs could well exceed the €800 Bn quoted by the Commission in the Offshore Renewable Energy Strategy in 2020 [32].

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We acknowledge the extremely helpful enthusiasm and professionalism of all colleagues in industry who so kindly accepted to be interviewed, in many cases during or very close to their holidays. It was noteworthy that very few of those contacted stated their unavailability for our work, which indicates clearly their great appreciation of its importance for the future of European renewable energy. It was our intent and is our hope to have fairly and fully represented your opinions within the constraints of the study, notably to apply the *Chatham House Rule* in all aspects of interviewees' identity in view of the business-critical nature of many topics discussed. If in some way you feel we failed, any and all criticism should be addressed to the author alone (e-mail to hanssen@1-tech.net), who will make an effort to issue post-publication report updates if and as appropriate. Thank you, dear colleagues.

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1-Tech (est. 1995) is a Brussels based SME with independent leading-edge expertise on energy and clean-tech for EU and international RD&D programmes. With its own research base, 1-Tech provides expert advice, studies and management support in clean energy. We consult on high-impact clean technologies, in particular emerging ones, and specialise in project design, consortium set-up and coaching, management support and Intellectual Property aspects, serving private- and public-sector innovators all across Europe.

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[31] "Annual steel consumption by the wind sector by technology, 2020-30", IHS Markit report 2021

[32] COM (2020) 741: An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future

Annex

Introduction & Interview questions circulated to interviewees for i-RES study August 2022.

The EU Member States are enacting measures for major increases in renewable energy installations in the coming years with targets expressed in GW new capacity for the year 2030 and further. The EP ITRE Committee proposes a 5% share of this capacity being reserved for **innovative RES**, with a draft definition that can be summarised as technology that improves in at least one way comparable **state-of-the-art** renewable technologies, or that makes exploitable a largely untapped renewable energy resource, but as of today is generally not able to attract low-cost private finance. [33]

The present study is conducted in order to collect reliable information from the RES energy sector for how much (how many GW) of innovative RES could be on the market by 2030 (with examples), and determine the appropriateness of "5%" as an indicative target.

Clarifications: our survey covers RES-based generation of electricity and heating/cooling) but not energy storage or distribution. The time scope of the study is limited to years from now to 2030 inclusive. As for accuracy, we ask you to be as precise as possible, with justifiable claims, noting that our resultant estimates for each class of i-RES will be rounded to the nearest 0.5GW capacity (0.2GW for 2023-26.)

Q1: **Which innovative RES technologies** do you foresee being brought to market in the years 2023 – 2026, inclusive? [By "being brought to market" you may include projects reaching a definite FID, as well as those expected to reach their COD, if any.]

Q2: **Under what assumptions** does the forecast you gave apply? [please be specific on assumptions relating to innovative RES; e.g. "simplified planning & permitting" applies to all RES, not just to i-RES]

Q3: **Why would the technologies you mentioned qualify as innovative**, in your opinion?
Please elaborate and comment on any issues but including

a. Your reasons for considering that there will be a market for the technologies
b. What cost they will be benchmarked against (if the technologies intend to compete on cost) [note that benchmark cost may be from a different sector, e.g. solar thermal vs. gas heating]

Q4: For technologies under development by your company (or, for non-developers, in your sector, country or region) **what is the expected new capacity to be installed for the timespan mentioned, in GW?** (or units appropriate for your segment: GW_p, GW_{th} or other) and **how do you foresee this capacity split between**

a. **EU27 Member States,** including active candidates – please specify for MS as far as possible
b. **European non-MS** (including UK, Norway, Switzerland, Turkey…)
c. **Asia/Pacific** and **North America**
d. **RoW** including MENA and LatAm

Q5: Apart from your own company/sector or geography, **are you aware of any other comparable or similar technologies** being developed by competitors/in other geographies, and do you know what

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[33] Please refer for the exact text to the relevant European Parliament amendments (Compromise Amendment 1 and Compromise Amendment 2).

generation capacity these intend to bring to market in the same period? If so, try to describe to same levels of accuracy.

Q6: Project yourself **forward to the next four years 2027 – 2030** inclusive. Then estimate

a. Would you still describe the technologies you just mentioned as innovative in the sense of the i-RES definition? If so, why? And, what new generating capacity do you foresee installed for the 2027-2030? (we mean new capacity, not cumulative to that for the previous period). Note: we shall insert zero GW for 2027-30 for these technologies in the report of our work if you see these move to being State-of-the-Art (or “mainstream”). Still, do feel free to make an estimate as this might be useful for an in-depth assessment of the efficacy of i-RES measures.

b. Do you foresee other technologies, closely related to those you just mentioned but not today ready to be included in your GW expectations/aims for 2023-26, which may reach that level in the time period 2027-30?

For question a.) please try to answer also Q4 and Q5 with comparable precision to that for the time period 2023-26 if possible.

Any other questions:

Please also comment if you see other aspects of the definition of i-RES that would be of relevance for the validity of your responses.