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Analysing the potential of citizen-financed community renewable energy to drive Europe's low-carbon energy transition

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ABSTRACT

In 2018, the real amount invested in the European Union's energy transition fell short of the funding level required to reach the 2030 climate and energy targets by €179 billion. Citizen-led finance in renewable energy development emerges as an innovative tool to bridge this investment gap. However, in spite of the European Union's ambition to involve local communities for co-driving the low-carbon energy transition, there is no comprehensive analysis quantifying citizens' potential to co-finance and participate in community renewable energy initiatives across Europe. We address this knowledge gap through a representative choice experiment survey that collected responses from 16,235 participants to different hypothetical investment options on renewable energy schemes across all European Union Member States, and estimate the social potential of European citizens to participate and invest in community-administered wind farms. Results from a novel survey-based social simulation indicate that €176 billion could be obtained from citizen-led finance in community-administered wind farm developments, enough to halve the investment gap to achieve a 32% renewable energy share in final energy consumption by 2030. Our analysis substantiates the case for facilitating easily accessible, risk-insured community investment options across Europe to unlock citizens' social potential for investing in community renewable energy.

1. Introduction

Launched in 2015, the Energy Union is the European Union's (EU) largest and most ambitious climate and energy legislative effort to fully decarbonise Europe's energy system by 2050, with a set of intermediate energy and climate targets for 2020 and 2030 [1]. The latter targets now reflect a 32% share of renewable energy (RE) in final energy consumption, a 32.5% improvement in energy efficiency, and a 40% reduction in greenhouse gas (GHG) emissions from 1990 baseline levels by 2030 [1]. However, tangible policy instruments and implementation mechanisms foreseen under current National Energy and Climate Plans (NECPs) for the period 2021–2030 remain inadequate for reaching the abovementioned targets [2,3]. In light of insufficient efforts, a viable pathway for decarbonisation at the extent necessary to reach climate neutrality by mid-century remains elusive. EU Member States (MSs) must therefore explore concrete and viable GHG emission reduction measures to successfully decarbonise their economies.

The investment requirements to realize such emission reductions are substantial and currently not being met [4]. Estimates indicate that about €380 billion are required annually over the next 10 years in order to achieve the EU's 2030 climate and energy targets, nearly double the 2018 investment level of €201 billion [4–6]. This resulted in an 'investment gap' of €179 billion for 2018. Estimates further project that no less than 9% of the foreseen annual investments, at least €34 billion per year, will have to finance the deployment of renewable power capacity to reach a 32% share of the EU's final energy consumption by 2030 [4]. This translates into a cumulative investment of €340 billion in renewable power capacity needed over the 2019–2030 period.

The EU aims to bridge the resulting investment gap through market-driven strategies that place citizens at the core of the Energy Union by having them "[…]take ownership of the energy transition, benefit from new technologies to reduce their bills, [and] participate actively in the market" [7, p. 2]. In that respect, citizen participation in community-based RE (CRE) generation through collective investment and shared ownership schemes, emerges as an innovative tool to unlock citizens' potential to contribute to bridging the existing investment gap. This positions CRE as a potentially important vehicle through which bottom-up, community-based climate mitigation actions can occur, and can thereby empower individual citizens to contribute towards Europe's

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Abbreviations

CE	Choice experiment
CO_2	Carbon dioxide
CRE	Community renewable energy
EU	European Union
EU-28	European Union's 27 Member States & United Kingdom
GDP	Gross Domestic Product
GHG	Greenhouse gas
$GtCO_2$	Gigatonnes of carbon dioxide
GW	Gigawatt
GWh	Gigawatt hour
LCOE	Levelised cost of electricity
LULUCF	Land Use, Land Use Change, and Forestry
MNL	Multinomial logit
MS	Member State
$MtCO_2$-eq	Million tonnes of carbon dioxide equivalent
MW	Megawatt
MWh	Megawatt hour
NECP	National Energy and Climate Plan
O&M	Operation and maintenance costs
RE	Renewable energy
RES	Renewable energy sources
RES-E	Electricity generated from renewable sources of energy
SBSS	Survey-Based Social Simulation
SME	Small and Medium-sized Enterprise
tCO_2-eq	Tonnes of carbon dioxide equivalent
TWh	Terawatt hour
USD	United States dollar
n	Individual person
i	Choice object
k	Alternative choice object
$V(.)$	Observable component in choice object
$\dot{\varepsilon}(.)$	Random component in choice object
Z_{in}	Object-specific attribute
S_n	Task-specific characteristic
U_{in}	Latent utility of individual n towards choice object i
U_{kn}	Latent utility of individual n towards alternative choice object k
N	Country sampled
r_N	profit rate (in %) of wind-based electricity generation in country N
P_N	Probability (in %) of representative individual in country N selecting an investment option
π_N	Social potential (in EUR) of representative individual in country N
b_N	Capital requirement requested (in EUR) to representative individual in country N
U_{AN}	Utility ascribed to choice object A by avg. individual in country N
U_{BN}	Utility ascribed to choice object B by avg. individual in country N
U_{CN}	Utility ascribed to choice object C by avg. individual in country N
ε_{in}	Error term
$\boldsymbol{\beta}$	Effect of object-specific attribute Z_{in} on the latent utility level U_{in} of individual respondent n
$\boldsymbol{\alpha}$	Effect of task-specific characteristic S_n on latent utility level U_{in} of individual respondent n
$\tilde{\pi}_N$	Country N's 'social potential' (in millions of EUR)
pop_N	Country N's population with a reasonable expectation to invest
$\widehat{F}_N$	Imputed choice probability (in %) under preferred investment configuration
$\widehat{\gamma}_{1N}$	Marginal effect on probability of selecting choice object A or B for a unit increase in capital requirement
$\widehat{\gamma}_{2N}$	Marginal effect on probability of selecting choice object A or B for a unit increase in profit rate
b_N^*	Optimal capital requirement b_N (in EUR) that maximises the social potential $\tilde{\pi}_N$ of representative individual of country N
P_N^*	Probability (in %) that representative individual of country N chooses to invest optimal capital requirement b_n^* into most preferred investment configuration

objective of carbon neutrality by mid-century.

Furthermore, CRE schemes can generate ancillary benefits for its owners and surrounding communities and thereby contribute to increasing social acceptance of clean energy alternatives [8–17]. Ancillary benefits may include additional sources of income from electricity sales or through dividends from the ownership of shares and/or land rent [11,18–20], lower energy costs derived from local or self-consumption [21], enhanced social cohesion and sense of community [22–24], and increased environmental awareness and stewardship [25], among others.

CRE can also lower the required investment amount for individuals vis-a-vis a fully self-owned system [12,16,17,26,27]. This may allow for under-privileged groups, such as lower income households or those who lack the proper infrastructure for a self-owned RE installation, to participate in RE generation. Along with this added benefit, citizen participation in CRE decreases social indifference and uncertainty towards new RE installations, an effect that can increase the social acceptance for new RE developments [28–32] and therefore expedite the low-carbon energy transition.

Illustrative of the documented socio-economic benefits attributed to CRE, various empirical studies have examined the factors influencing citizen driven RE developments within national contexts. For instance Ref. [33], categorise the changing characteristics and evolving ownership structure of citizen-owned wind turbines and district heating systems across Denmark between 1975 and 2016. Along similar lines, Ref. [34] estimate the relative effect of different socio-economic, environmental, and institutional determinants behind RE cooperative members in northern Belgium. In addition Ref. [35], conduct an estimation of financial and non-financial factors driving homeowners' purchasing preferences for different PV module applications, and further assess potential demand increases based on homeowners' different 'willingness to pay' values. Similarly Ref. [36], investigate citizen preferences for investing in different RE project configurations in Ireland, aggregating individual investment estimations to assess the relative contribution of citizen finance for covering the investment needs of large, utility-scale developments. Their enquiry is complemented by Ref. [37], who examine the influence that heterogenous individual perceptions of France's RE sector have in driving citizen participation in collective RE investment platforms.

The previous works on CRE participation, documented above, are limited to national contexts. This paper adds to this literature by offering an aggregate understanding of the potential impacts and participation in CRE across the EU, which also allows for cross-country comparisons due to the use of a common methodology employed in each nation. The only other attempt at such a quantification at the European level comes from Ref. [38], who use country-level data for estimating the potential number of wind and solar RE prosumers (consumers and producers of RE) throughout Europe and across a broad base of single and collective

ownership arrangements including self-ownership, CRE, public ownership and small & medium-sized (SME) firm adoption.

Specifically Ref. [38], use the database of the European federation for RE cooperatives (REScoop[1]) for identifying collective ownership schemes in each EU MS. For countries lacking available data on such schemes, the authors take the average value of The Netherlands and France and generate the corresponding variable for the country in question. Such an approach leaves their estimation exercise with an important shortcoming. Further, the authors assume limited single ownership of wind power assets and thus focus solely on solar technology for quantifying single ownership schemes. In order to do so they use data from the EurObserv'ER consortium's[2] 'solar photovoltaic barometer' to obtain values for solar PV installed capacity and electricity generation, which they then divide into different installation sizes to categorise and estimate the individual ownership share of households, SME firms, and public entities. Assuming a 100% RE scenario, the authors estimate that about 113 million households could become prosumers across the EU by 2050. However, the study does not fully consider the participation decisions of households to adopt or not adopt a RE technology, and further assumes that a hypothetical financial investment per household is a function of average savings rates alone.[3]

The present study thus contributes to the abovementioned literature by investigating the optimal combination of different financial attributes and operational configurations that maximise citizen investments in community-based RE generation schemes. We quantify the resulting investment volumes and aggregate them across the EU-28 to estimate European citizens' aggregated financial participation in CRE, defined as the 'social potential'. The extent to which the EU's social potential for CRE financing can bridge the investment gap and contribute to reaching the 2030 RES target is then assessed.

For this purpose, data from a choice experiment (CE) conducted across all EU-28 is used, where respondents are presented with different investment options to co-finance RE schemes with different characteristics and varying attributes. Using imputed choice probabilities derived from multinomial logit (MNL) estimates on the CE data, we compute the social potential as the expected investment from the representative citizen of each EU MS. We call this process Survey-Based Social Simulation (SBSS).

Section 2 introduces the CE as our main data collection tool. Section 3 describes the SBSS methodology. In section 4, we present the results stemming from our analytical procedure, assess the potential of our estimated citizen financial participation in CRE, and further discuss caveats to our methodology. In section 5, we explore the effects of existing RE subsidies on our estimated social potential, and reflect on the policy implications of our results. Section 6 concludes.

2. Data collection

The main data utilised for this study was obtained from the responses to a choice experiment conducted as part of an international online survey with private citizens across 31 countries (EU-28,[4] Norway, Switzerland, and Turkey). The internet-based survey was distributed to about 600 respondents in each EU MS through a random sampling procedure that relied on email panels, with a total final sample of 16,235 respondents. Respondents were recruited using a compensation mechanism of at least €5 per person to incentive participation and ensure that not only people with energy interests made up the sample. As shown in table A1 (see Supplementary Materials), quotas were set from national sociodemographic indicators pertaining to age [39,40], gender [41], and income levels [42] in order to ensure the representability of the samples for all countries. Importantly, the sampling procedure aims to produce representative samples for each nation, and therefore is not weighted according to national population. The smaller samples in Malta and Cyprus reflect the difficulty, and expense, of sampling in these nations, not population weighting. Furthermore, to frame our study in the context of EU climate and energy targets, responses from Norway, Switzerland and Turkey were dropped.

The purpose of the CE was to identify respondents' levels of interest in participating in a community-based investment scheme to finance solar or wind projects, and to investigate what specific set of investment attributes of RE initiatives, including financial and operational conditions, drive citizen participation. Survey respondents were presented with eight different choice tasks, each one displaying a total of three choice objects to choose from: two hypothetical investment opportunities (object A, object B), and a third "opt-out" option (object C) provided in the case where a respondent had no interest to invest. Respondents were asked to choose which of these three choice objects they would prefer if confronted with the same situation in real life. The choice tasks were built following a D-efficiency criteria [43], and organized into three blocks of eight choice tasks. Each respondent was presented the choice tasks from a randomly selected block in a random order,[5] and asked to pick one choice object for each of the eight different choice tasks. This resulted in eight different choices per respondent and a final sample of 129,880 choice responses selected from 389,640 different choice objects available.

As specified in Table 1 below, each choice task included two task-specific characteristics that applied to all three choice objects (A, B, and C) within a given task. Task-specific characteristics included the required initial investment (or capital requirement) and the RE technology to be installed (either wind or solar). While the RE technology varied between choice tasks with a 50/50 split, the capital requirement did not – each respondent faced the same capital requirement for the entire choice task to ease the cognitive burden. This effectively splits the sample into five sub-samples based on capital requirement.

In addition, the choice tasks included four object-specific attributes that varied between choice objects A and B, with choice object C as the default opt-out alternative where all attribute variables are set to zero. The four object-specific attributes were chosen based on key issues identified in the literature as being both policy relevant and highly salient for traditional and non-traditional investors. As specified in Table 1, the remuneration obtained by the respondent's investment is represented by the 'profit rate' attribute, while the 'holding period' defines the length of time until the investment is repaid. The 'visibility' attribute captures viewshed effects related to the installation, while the 'administrator' attribute makes reference to the preferred organization for administering the RE development. These last two attributes were a necessary addition to the CE design setting as both have been shown to be key drivers shaping RE adoption [27].

Figure A1 in the Supplementary Materials offers an example of one of

[1] https://www.rescoop.eu/.

[2] https://www.eurobserv-er.org/.

[3] [38]state their estimation method as follows: "The Eurobarometer contains statistics on which topics concern citizens the most. By selecting the relevant topics, the share of households that will want to invest in renewable energy is estimated. The total amount this group can invest is limited by multiplying their normalized average savings rate between 1995 and 2015 with an estimated minimal and maximum amount each household will invest yearly" (p.13). No further information on this methodology is given in their report.

[4] This study was completed before the United Kingdom (UK) left the EU. We therefore refer to the EU as the EU-28, including the UK.

[5] For a full description of the choice experiment design, testing and results please see Ref. [26].

[6] The CE defined "investments" as lump sum money transfers that are to be fully repaid at the conclusion of the holding period. This specificity allowed to disentangle the profit rate from the holding period and avoided the necessity to consider compounded interest, thereby simplifying the set of considerations that respondents had to account for when evaluating the profitability and, by extension, the preferred choice object.

Table 1
Task-specific and object-specific attributes, along with their descriptions and range of values.

Investment & operational attributes	Description	Values
RE installation	The type of renewable energy project the respondent is investing in.	• Wind farm • Solar park
Capital requirement	A randomly assigned, risk-free investment amount the respondent has to pay to join any of the investment opportunities being offered.	• €100 • €500 • €1000 • €2000 • €5000
Profit rate	A one-time lump sum payment to the respondent at the conclusion of the holding period, when the RE project is finalised. Displayed as a real rate of return on the initial investment that already accounts for inflation[6].	• 0% • 10% • 20% • 50%
Holding period	The number of years elapsed until the respondent's initial investment and the profit generated from it are both repaid.	• 5 years • 10 years • 15 years
Visibility	Whether or not the RE installation is visible from the respondent's home.	• Visible • Not visible
Administrator	The legal entity overseeing the respondent's investment and in charge of building and administering the RE installation.	• Community organization (e.g. energy cooperative) • Utility company • Government entity (e.g. municipality)

the eight choice tasks utilised in the CE and as shown to English-speaking survey respondents, along with a descriptive script introducing the CE exercise and explaining the choice task and premise of the investment options (choice objects).

Table 2 below showcases the distribution of responses obtained from CE participants. The left column indicates the share of respondents who chose an investment option (choice object A or B) at least once throughout the CE, while the right column specifies the total share (percentage) of investment options selected by respondents in each EU MS.

Overall, CE responses indicate a substantial interest expressed by respondents for participating in CRE developments via collective finance and co-ownership schemes: 79% of respondents selected at least one investment option (choice object A or B), and further chose to invest in almost 60% of all available options. While this implies a high interest for CRE alternatives as a social innovation in energy financing, it is important to note that our experimental design assumes full (albeit imperfect) access to robust market information and risk-free community investment options operationalised through a trustworthy and straightforward financial vehicle. These facts, along with the availability of multiple investment options, offer a plausible explanation for the high acceptance manifested for the investment offerings. We note specifically that 19 MSs sampled in the CE have the majority of their respondents choosing an investment option in over half of all choice tasks presented to them, while only 9 MSs host majorities choosing not to invest in more than half of choice tasks.

Interestingly, survey countries with a higher observed interest in joining CRE initiatives (e.g. Bulgaria, Croatia, Romania, Slovenia, Hungary, Estonia) correlate with lower installed wind power capacities per capita, while countries expressing a lower interest (e.g. Denmark, Sweden, Germany, United Kingdom, Spain, Finland) have higher wind capacity installations per capita (correlation coefficient = −0.942, based on [44,45]).[7] This initial assessment points toward a potential trade-off between installed capacity and investor acceptance levels (as manifested by a lower willingness to co-invest in CRE initiatives), indicating an inversely proportional relationship between both variables.

Table 2
Descriptive statistics of responses to investment options in the EU-28.

Country	Pct. of respondents selecting at least one investment option	Total pct. of investment options selected
Austria	82%	57%
Belgium	71%	48%
Bulgaria	88%	64%
Croatia	95%	80%
Cyprus	82%	60%
Czech Rep.	80%	56%
Denmark	64%	44%
Estonia	91%	84%
Finland	74%	46%
France	71%	48%
Germany	74%	49%
Greece	88%	62%
Hungary	84%	60%
Ireland	81%	51%
Italy	83%	61%
Latvia	68%	44%
Lithuania	80%	58%
Luxembourg	83%	62%
Malta	90%	64%
Poland	76%	55%
Portugal	81%	59%
Romania	86%	67%
Slovakia	80%	55%
Slovenia	82%	63%
Spain	75%	49%
Sweden	64%	44%
The Netherlands	76%	58%
UK	73%	46%
EU-28	**79%**	**57%**

It further suggests that collective investments on RE initiatives are seen favourably as viable financial instruments in nations where public acceptance issues accompanying new energy infrastructure are not yet strongly rooted [46]. Alternatively, countries manifesting low interest may be illustrative of small-scale energy investment constraints due to prohibitive capital investment requirements [47,48]. This may be further exacerbated by a combination of stricter spatial planning criteria [47,49], lengthy permitting procedures and legal disputes [50,51], and increasingly stringent RE compensation mechanisms [52], particularly in countries with long-standing traditions of cooperative association such as Denmark and Germany.

3. Methodology

CEs are a well-suited data generation method for modelling and interpreting respondents' choice dynamics using probability-based discrete choice models to account for people's preferences and decision-making processes [53–57]. CEs are grounded in economic random utility theory, which assumes that the utility level person *n*

[7] Correlation coefficient obtained by first dividing EU-28's installed wind power capacities [44] by their corresponding national populations [45]. The resulting figures (installed wind power capacity per capita for every EU-28) were then correlated with the figures listed in column 3 from Table 2 (Total pct. of investment options selected).

experiences from choice object i can be separated into one observable $V(.)$ and a random $\dot{\varepsilon}(.)$ component [54]. In our analysis, both components are a function of the object-specific attributes Z_{in}, and the task-specific characteristics S_n (both described in Table 1). As such, the latent utility U_{in} from any choice object can be expressed as:

$$U_{in} = V(Z_{in}, S_n) + \dot{\varepsilon}(Z_{in}, S_n) \quad (1)$$

Based on equation (1), we can assume that any choice object i will be preferred/selected over some other choice objects k, if individual n's utility for i (U_{in}) is greater than the utility assigned to all other competing choice objects k ($U_{in} > U_{kn}$). Thus, by relating the observed choices to the choice object attributes in Table 1, the preferences of respondents for specific attribute levels can be estimated via choice modelling techniques.

Following the theoretically-grounded rationale of random utility, a methodologically-structured, three-step probabilistic simulation technique called 'Survey-Based Social Simulation' (SBSS) is developed to estimate European nations *social potential* to collectively finance and co-participate in CRE initiatives. The aim is to identify the maximum possible capital offering available to be invested in CRE generation schemes by the representative citizen in each EU MS under an ideal configuration of the financial and operational attributes outlined in Table 1. Mathematically, this individual (per person) social potential is defined as π_N in (2). In what follows, the subscript n is substituted for N, as we calibrate the SBSS method on the representative individual of each nation N, as opposed to individual respondents (n).

In order to calculate the individual social potential (π_N) we first impute the probability (P_N) that the representative individual in country N chooses an investment option and then multiply this value by the capital requirement (b_N) that the individual is asked to contribute to for co-financing an RE installation. This yields the expected investment per citizen of country N as expressed in (2).

$$\pi_N = P_N b_N \quad (2)$$

Equation (3) defines the probability P_N that the representative individual of country N will invest in a choice object with a capital requirement b_N as a result of he/she ascribing a higher utility U to any one choice object (A or B) than to opting-out (choice object C).

$$P_N = Prob(U_{AN} > U_{CN} | U_{BN} > U_{CN}) \quad (3)$$

The computation of choice probabilities, P_N, is accomplished by imputing the average probability of choosing object A or B from discrete choice multinomial logit (MNL) models estimated on the CE data. The imputations are based on a choice object with the feasible, preferred configuration of attributes defined in Step 1 below.

3.1. Estimating the social potential

Employing the SBSS entails the use of choice model parameter estimates to impute choice probabilities given the effects of different combinations between object-specific attributes and task-specific characteristics, and maximizing some objective function subject to these imputed probabilities. This allows to estimate both the probability that any one specific choice object under any given choice task is selected instead of competing alternatives, and the changes in this probability given some specified modifications in the design settings. Assuming the latent utility in (1) is linear with respect to the explanatory variables and that the error term ε_{in} takes a Gumbel extreme value distribution, leads to the adoption of the alternative specific multinomial logit model (MNL) in (4) – the common workhorse model for discrete choice frameworks.

$$U_{in} = Z_{in}\boldsymbol{\beta} + S_n\boldsymbol{\alpha}_i + \varepsilon_{in} \quad (4)$$

Effectively, the MNL models the probability of a discrete choice outcome as a function of the object-specific set of attributes Z_{in} and the task-specific characteristics S_n. The effects of the variables within Z_{in} and S_n on the latent utility levels U_{in} of respondent n are represented by the vectors $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}_i$. Since the core interest lies in the decision to invest vs. not invest, choice object C (opting out) is set as the base alternative and assigned a value of zero to its corresponding coefficient vector $\boldsymbol{\alpha}_i$. This allows to more easily interpret the output of the MNL as the effects ($\boldsymbol{\beta}$ and $\boldsymbol{\alpha}_i$) that the different variables from choice and task-specific attributes (Z_{in}, U_{in}) have on the probability of opting-out from an investment option (choice objects A or B) presented in the choice task.

3.1.1. Step 1: estimating the effects of choice attribute variables on choice probabilities

Equation (4) is estimated via maximum likelihood estimation of the full dataset from the entire CE sample in order to estimate the parameters of $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}_i$, as the average effects of the attribute variables in Table 1 over the representative sample of respondents in the EU-28. Specifically, the 'object-specific attributes' listed in Table 1 are contained in Z_{in}, with the 'visibility' attribute represented as a dummy variable (= 1 if the installation is visible from the respondent's home, 0 otherwise), and the 'administrator' attribute represented as two dummy variables, one representing community-administered installations and one representing government-administered developments with utility company installations serving as the omitted variable. Further, the 'RE technology' attribute within S_n is represented by a dummy variable that takes a value of one if the choice task references a solar farm, while the 'capital requirement' attribute contains the Euro value that the respondent was required to pay to join the hypothetical investment. Additionally, within S_n alternative-specific constants for choice objects A and B are included (with choice object C as the omitted category), and country-level fixed effects are further added in the full sample model. Together these variables control for any systematic response biases due to unobserved factors at the country (e.g. financial culture) or choice object (e.g. ordering of objects)[8] levels.

The outcome stemming from this initial estimation allows to identify the most preferred set of variables on average over the full sample model. These variables are bundled together and used as the most preferred investment configuration that maximises the probability of accepting an investment option by the average, representative individual for funding a CRE scheme, for each sampled country N.

For the other two object-specific attributes in Z_{in} (holding period and profit rate) we select values reflecting the real market conditions and energy productivity ratings related to wind power technology of all EU-28 MSs. Therefore, the holding period is set at a conservative value of 20 years for all countries, as this reflects the working lifespan of wind turbines and the point at which they might get dismounted and either disassembled or refurbished [58]. The profit rate differs from country to country depending on variations of prevailing energy market conditions and different national wind energy productivity ratings. As shown in table A2 (see Supplementary Materials), the calculation of the profit rates is thus conducted using country-specific values through the following process:

1) Firstly, the EU's total investments on wind energy for 2017 (€ 22.3 billion) [59] are divided by its corresponding installed wind power capacity (11.5 GW) for that same year [44]. The resulting figure (€ 1939.13/kW) illustrates the European average of total installed generation capacity costs for wind-based electricity generation,[9] and used as the default value for all EU-28 and the UK.

[8] There is no need to include additional task-specific variables in S (such as age, household income levels, gender, etc.); since at this stage the primary interest lies in aggregating results at the country-level, and country-level trends and characteristics are captured by country-level fixed effects.

[9] The resulting figure reflects IRENA's [74] own value for the total installed costs for onshore wind projects in Europe during 2018.

2) To obtain the country-specific productivity ratings of installed wind power capacity, the values from the wind-based electricity generated (GWh) by each MS in 2017 [60] are taken and divided by the country's installed wind power capacity (GW) [44] for that same year.
3) The 2018 average spot electricity price (€/GWh) for each MS is then taken from the different electricity markets servicing the corresponding countries [61–72].
4) Taking the information obtained in steps 2–3 allows to calculate each country's average annual revenue (expressed in EUR) from the generation and sale of electricity per GW of installed wind power capacity.
5) With this information, the market profit rate (r_N) for each country N is calculated as follows:

$$profitrate(r_N) = \frac{avg.\ annualrevenue - installedcapacitycosts}{installedcapacitycosts} \times 20years \times 100$$

Adding the 'holding period' and 'profit rate' variables to the most preferred investment configuration by the average individual CE participant results in: *a 20-year investment into a visible wind farm managed by a community administrator and with a market-determined profit rate*.

It is important to note the limitations faced when calculating the profit rates of each country sampled. Particularly relevant is the omission of operation and maintenance (O&M) costs in the calculation of 'European average total installed generation capacity costs' (step 1 above), as these can represent up to 20–25% of the levelised cost of electricity (LCOE) of wind power [73]. A more accurate appraisal of wind power costs across the value chain would thus account for O&M costs which, according to Ref. [73], in Europe these stood at between 0.013 and 0.025 USD/kWh on average in 2010. As such, future empirical research could instead appraise wind power costs by, for instance, taking the weighted average LCOE as the main reference cost value. For Europe, this stood at 0.07 USD/kWh in 2018 [74].

3.1.2. Step 2: imputing the probability of accepting an investment option

Following from step 1, the most preferred attribute levels identified and defined in Step 1 are input into equation (4) to then compute the probability P_N of accepting the most preferred investment configuration outlined above. Important to note that up until this stage the analytical procedure has not yet considered the other critical quantity for estimating the individual social potential (π_N); that is, the average capital invested per person (b_N). This is formally shown in equation (5) by expressing P_N *as* a linear function of the capital requirement b_N of the selected investment option (choice objects A or B) and the market-determined profit rate (r_N) offered along with b_N.

$$P_N = \widehat{F_N} + \hat{\gamma}_{1N} b_N + \hat{\gamma}_{2N}(b_N r_N) \tag{5}$$

$$P_N = \widehat{F_N} + b_N(\hat{\gamma}_{1N} + \hat{\gamma}_{2N} r_N)$$

Imputed choice probabilities are estimated as $\widehat{F}_N$ under the preferred investment configuration defined under Step 1 using parameter estimates from country-specific MNL models that contain variables of all the attributes listed in Table 1. In the imputation of choice probabilities on the object-specific variables Z_{in} and task-specific variables S_n are set as to make equation (5) true even when there is a capital requirement asked for of $b_N = 0$. Therefore, $\widehat{F}_N$ depicts the imputed probability of selecting choice object A or B under the most preferred investment configuration defined in Step 1 and a capital requirement of zero. Feasible values of all attributes from Table 1 are thus accounted for, except for the capital requirement – which is allowed to vary under a two-variable maximization framework described in Step 3. For this application, the settings for imputing $\widehat{F}_N$ illustrate a visible wind farm with a 20-year holding period, managed by a community administrator and with an initial capital requirement of zero. Equation (4) is re-estimated 28 times (once for each country N in the sample), imputing $\widehat{F}_N$ in each case and estimating $\hat{\gamma}_{1N}$ and $\hat{\gamma}_{2N}$, the estimated marginal effects on the probability of selecting choice object A or B for a unit increase in capital requirement and profit rate, respectively.

3.1.3. Step 3: maximizing the expected funds collected per country

The outcome of step 2 above allows to proceed with the calculation of the optimal investment requirement to ask from the representative individual in each nation N based on the most preferred variables inputted in the simulation of the MNL model. As such, $\tilde{\pi}_N$ is defined as the country N's 'social potential' for investing and participating in community-administered wind farm cooperatives, with pop_N indicating country N's population with a reasonable expectation to invest (ages 25–64).[10]

$$\tilde{\pi}_N = (P_N b_N) pop_N \tag{6}$$

In spite of the stated aim to maximise $\tilde{\pi}_N$, for now the population component is ignored and instead return to π_N from (2), which considers only the representative individual from each sampled nation. We thus face a two-variable maximization problem, where the object is thus to maximise (2) with respect to the representative probability P_N and capital requirement b_N, yet constrained by the relationship in (5). Substituting (5) into (2) results in (7):

$$\pi_N = b_N[\widehat{F}_N + b_N(\hat{\gamma}_{1N} + \hat{\gamma}_{2N} r_N)] \tag{7}$$

Taking the first derivative of (7) with respect to b_n results in (8):

$$\frac{\alpha\pi}{\alpha b} = \widehat{F}_N + 2b_N(\hat{\gamma}_{1N} + \hat{\gamma}_{2N} r_N) \tag{8}$$

By setting (8) equal to zero and solving for b_N an analytical solution is obtained for the optimal capital requirement (expressed as b_N^*) that maximises the expected capital offering $\tilde{\pi}_N$ that the representative individual from country N is willing to provide[11]:

$$b_N^* = \frac{-\widehat{F}_N}{2(\hat{\gamma}_{1N} + \hat{\gamma}_{2N} r_N)}$$

The optimal capital requirement b_N^* is input back into equation (5) and solved in order to obtain the probability P_N^* that a representative citizen of country N chooses to invests capital level b_n^* into a community-administered wind farm, with a 20-year holding period and a market-based profit rate. Inputting b_N^* and P_N^* into (6) and solving results in the final estimation of the social potential ($\tilde{\pi}_N$) for investing and participating in community-administered wind farms in each nation N.

4. Results

4.1. The most preferred investment attributes

Following from section 3.1.1 above, the results of an initial estimation of the MNL in (4) on the full dataset from all 28 EU MSs is reported here. The coefficients of the attribute variables ($\boldsymbol{\beta}$ and $\boldsymbol{\alpha}_i$ effects) are converted into marginal effects and shown in Table 3 below.

Table 3 shows that, on average, European citizens strongly prefer a community-owned legal entity (e.g. energy cooperative) for administering the RE installation they invest in over government or utility

[10] For the purposes of this research, all individuals between 25 and 64 years of age were taken as the representative population with a reasonable expectation to invest for all 28 EU MSs sampled in the CE (including the UK). Numbers were calculated based on national demographic data obtained from Refs. [40,45].
[11] The $\pi_n(b_n)$ functions are concave down for each nation N, verifying that the analysis gives maximum values of these functions.

company administrators. In spite of high heterogeneity, there is a slight overall inclination for wind farms over solar parks as the preferred technology to invest in; this is likely region-specific, as explored in Ref. [26]. European citizens are also more willing to invest if they see the RE installation from their household. As expected, higher profit rates make the investments more preferable. Specifically, for every additional €100 obtained as profit, we observe a corresponding 2.7% increase in willingness to invest. Finally, longer holding periods make investment options less attractive: willingness to invest decreases by 2.2% for each added year that the respondent's capital is held.

These attributes represent the most preferred variables that, when combined with the market-derived values obtained for the 'holding period' and 'profit rate' variables, maximise the level of investment collected by the average representative individual citizen in every MS and across the EU. Conclusively, the 'optimal' investment option that maximises the probability the average European citizen co-invests in a CRE initiative showcases a *20-year investment on a community-administered wind farm, visible to the investor, and offering a country-specific market-based (unsubsidized) annual profit rate* for all cases. Profit rates differ from country to country depending on variations of prevailing energy market conditions and different national wind energy productivity ratings, and are illustrated in table A2 (see Supplementary Materials).

4.2. The social potential for wind farm cooperatives in the EU-28

Following the analytical steps outlined in sections 3.1.2 and 3.1.3 the investment potential for the optimal investment scenario (identified above) is computed. This calculation relies on country-specific unsubsidized profit rates, shown in table A2 (see Supplementary Materials). Individually-obtained funds are then multiplied by each country's population with a reasonable expectation to invest (aged between 25 and 64) to obtain the social potential of each MS. The results obtained at the conclusion of this analytical process and the summations across the entire EU-28 are illustrated in Table 4 below.

Results indicate a substantial EU social potential for citizen-led financing of community-administered wind farms under current market conditions – that is, without subsidies or any other national support mechanism. Consequently, up to €176 billion could potentially be harnessed from European citizens to support community-based forms of RES development, and thereby increase the deployment of clean energy and expedite Europe's low-carbon energy transition.

Furthermore, the imputed probability that a given respondent accepts the optimal investment option is 20% across the entire sample. With the caveat that this average probability is not weighted by country population sizes, this result suggests that about one in five European citizens would be willing to invest in a feasibly configured community-administered wind farm development. Relevant to note the heterogeneity in the expected collection per citizen (π_N), where generally nations with lower wind power capacities show higher values. This corresponds with the descriptive results obtained from the CE responses (Table 2), which are interpreted here as an increased interest from citizens in EU MSs with low wind power capacities to have access to low-risk, trustworthy investment options in this technology.

Furthermore, heterogeneity in expected citizen investments ($[\pi_N]$ in Table 4) is driven largely by differences in country specific *unsubsidized* profit rates (calculated in table A2 of the Supplementary Materials), and by the observed interest in the hypothetical RE investments from the CE (Table 2). Country-specific profit rates are in turn driven by differences in electricity prices and wind resource availability between nations.

The heterogeneous interest in the CE investments observed across nations in the survey countries likely stems from many unobserved factors such as culture, available investments, the prevalence of community-led initiatives, and national savings rates. As noted in section 2, nations with a higher observed interest in joining RE initiatives (e.g. Bulgaria, Croatia, Romania, Slovenia, Hungary, Estonia) correlate with lower installed wind power capacities per capita, while countries expressing a lower interest (e.g. Denmark, Sweden, Germany, United Kingdom, Spain, Finland) have higher wind capacity installations per capita, indicating a negative relationship between these factors.

4.3. Bridging the investment gap

As shown in Fig. 1 below, current estimates indicate an investment gap of €179 billion annually to achieve the EU's 2030 climate and energy targets [1,5]. No less than 9% of the foreseen annual investments over the next 10 years (2020–2030) – at least €34 billion annually – will have to finance the deployment of RES generation capacity in order to reach a 32% share of the EU's gross final energy consumption by 2030 [4]. This translates into a cumulative investment of €340 billion over the next decade, and positions the EU's social potential of €176 billion for investing and participating in CRE as a potentially critical resource to bridge the existing investment gap.

As depicted in Fig. 1 above, the social potential of €176 billion that European citizens could contribute with through collective investment schemes in CRE respond directly to this need. When evenly distributed throughout the 10-year timespan mentioned above, they result in an annual investment of €17.6 billion, enough to halve the investment requirements foreseen to achieve a 32% RES share by 2030. In light of this huge potential, the EU's energy-related carbon mitigation efforts could greatly benefit from the proactive financial participation and involvement of European citizens. Policies that reach out to and unlock this potential are therefore desirable and should be carefully considered for a timely, cost-effective, and participatory implementation of a low-carbon energy system. This is further explored in section 5 below.

4.4. Limitations and caveats

The analytical process and simulation procedure for estimating the social potential is subject to various caveats. Most notably, realizing the social potentials shown in Table 4 requires that all citizens have access to community investment options provided by reliable institutions. This is not currently the case in all EU MSs.

Furthermore, while the SBSS imputation was conducted using national profit rates calculated from national indicators, it likely falls short of capturing the national market conditions facing wind investments, as it is subject to data limitations and assumptions as noted in section 3.1.1.

Notably, RES support mechanisms are not included in the main results and are considered in the sensitivity analysis in section 5.1. However, the 'subsidised' social potential calculated in section 5.1 is based only on state-level national support schemes [75] and omits regional or municipal support mechanisms that may drive CRE uptake and associated profit rates. Furthermore, these national support schemes illustrate the total volume of state subsidies aggregated across all RES technologies. The analysis conducted in this study therefore takes this aggregate value for wind energy technology only. Future studies could thus disaggregate national support schemes according to different RES

Table 3
Marginal effect on probability of not selecting choice object C (i.e. choosing to invest) across full sample. Variables correspond to the CE attributes in Table 1. Model estimated using 389,640 observations from 129,880 choice task responses from 16,235 respondents. Model also contains country fixed effects terms. Standard errors estimated with clustering at the respondent level.

Variable	Coefficient	Std. Err.	P-value
Capital requirement	−0.00006	2.10E-06	0
Profit	0.00027	3.70E-06	0
Holding period	−0.0217	0.0003	0
Visibility	0.0059	0.0019	0.002
Solar farm	−0.0177	0.0019	0
Gov. admin.	−0.0025	0.0026	0.342
Community admin.	0.0315	0.0026	0

Table 4
The social potential of the EU-28 under market-based investment profit rates (see table A2 in the Supplementary Materials).

Country	Optimal capital requirement[a] (b_N^*)	Probability of investing (P_N^*)	Expected collection per citizen (π_N)	Pop. expected to invest[b] (pop_N)	Social potential: total expected funding collected[c] ($\bar{\pi}_N$)
Austria	€ 3560.18	21.20%	€ 754.73	4,877,713	€ 3681.35
Belgium	€ 3087.35	12.01%	€ 370.94	6,016,415	€ 2231.73
Bulgaria	€ 4050.47	22.80%	€ 923.66	3,969,939	€ 3666.87
Croatia	€ 8526.89	35.05%	€ 2988.28	2,268,200	€ 6778.03
Cyprus	€ 2797.81	28.93%	€ 809.47	465,867	€ 377.11
Czech Rep.	€ 2747.61	16.70%	€ 458.86	5,934,718	€ 2723.21
Denmark	€ 6383.83	13.53%	€ 863.51	2,949,119	€ 2546.58
Estonia	€ 5955.53	34.68%	€ 2065.57	718,337	€ 1483.78
Finland	€ 2466.23	14.28%	€ 352.22	2,828,695	€ 996.32
France	€ 2774.88	13.47%	€ 373.90	33,896,476	€ 12,674.02
Germany	€ 3488.24	12.99%	€ 453.20	45,221,866	€ 20,494.59
Greece	€ 3127.40	27.02%	€ 845.09	5,804,056	€ 4904.92
Hungary	€ 2908.52	20.93%	€ 608.66	5,457,241	€ 3321.61
Ireland	€ 3110.32	13.99%	€ 435.22	2,545,292	€ 1107.77
Italy	€ 3622.99	23.00%	€ 833.32	32,960,658	€ 27,466.93
Latvia	€ 2740.04	14.73%	€ 403.72	1,070,614	€ 432.23
Lithuania	€ 4082.34	21.51%	€ 878.10	1,540,716	€ 1352.90
Luxembourg	€ 3562.16	26.02%	€ 926.85	340,815	€ 315.88
Malta	€ 3536.38	18.42%	€ 651.29	254,544	€ 165.78
Poland	€ 4287.00	18.41%	€ 789.08	21,758,508	€ 17,169.12
Portugal	€ 3480.66	20.85%	€ 725.77	5,587,789	€ 4055.46
Romania	€ 6444.75	30.00%	€ 1933.45	10,992,372	€ 21,253.21
Slovakia	€ 2745.70	15.52%	€ 426.25	3,168,805	€ 1350.69
Slovenia	€ 4517.52	26.68%	€ 1205.23	1,171,362	€ 1411.76
Spain	€ 3013.60	15.94%	€ 480.38	26,194,723	€ 12,583.30
Sweden	€ 4248.38	15.19%	€ 645.49	5,087,533	€ 3283.94
The Netherlands	€ 3729.50	15.07%	€ 562.16	9,036,117	€ 5079.75
UK	€ 2724.97	14.35%	€ 391.12	34,154,649	€ 13,358.72
EU-28	**€ 3847.19**	**20.12%**	**€ 638.02**	**276,273,139**	**€ 176,267.55**

[a] Wind farm, 20-year holding period, market-based profit rate, visible, community-administered.
[b] Aged between 25-64.
[c] In millions of EUR.

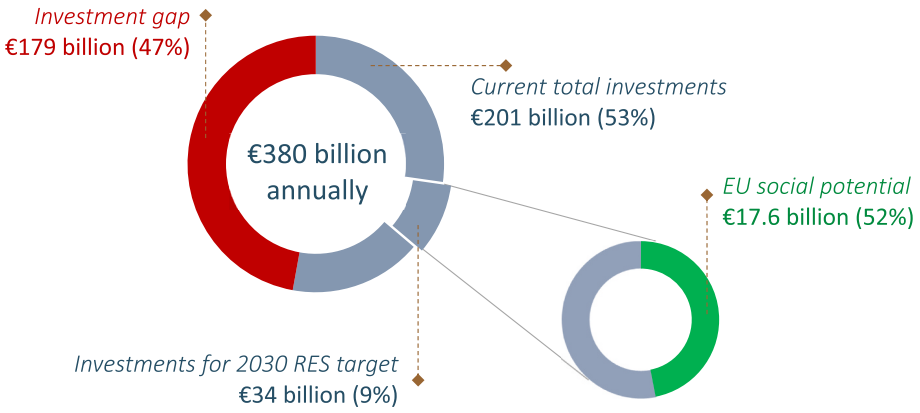


Fig. 1. Estimated annual investments between 2019 and 2030 to achieve EU 2030 climate & energy targets, with specific investment requirements to reach 2030 RES target, plus annual contribution from EU social potential.
Source: Own elaboration.

technologies in order to offer a more accurate account of the effect of state subsidies on wind energy development profit rate estimations.

However, taking section 5.1 as a sensitivity analysis regarding the assumptions on profit rate shows that only modest changes in estimated social potentials would come from reasonable variations of profit rates. In contrast, the holding period is fixed for every country at 20 years. Switching to a non-fixed holding period for the simulation procedure would provide a more flexible maximization framework that would most likely result in a generalised increase of the estimated social potentials for every sampled country.

The same rationale could be employed when calibrating the 'RE technology' variable: based on the responses obtained, the analytical process takes the most preferred RE technology/installation on average across the EU-28, despite the potential for regional heterogeneity in this dimension. The proposed SBSS methodology allows for a more refined analysis by disaggregation in many dimensions, including in the dimension of the preferred RE technology on a country basis to determine whether some countries prefer solar or wind technologies. This might lead, again, to an overall increase of the estimated social potential (albeit only in countries with a strong preference for solar investments). The CE gave each respondent eight choice tasks, but stipulated that the respondent consider them separately, not as additional investments to those already chosen in the exercise. For this reason, one single RE technology (wind) is considered as the object of investment.

Simultaneously considering solar technology would violate this condition of the CE and in effect 'double-count' the willingness of respondents to participate in some CRE schemes.

In the same vein, the optimal capital requirement was calculated to be nation-specific, as the analysis focuses on the representative individual of each sampled country. However, future SBSS work could further disaggregate by income bracket, gender or age. In the present case this would result in a more appealing investment proposition being offered to different groups of citizens and would again likely lead to an overall increase in the estimated social potential.

All these measures, when combined, would likely increase individual respondents' investment probabilities, as well as the quantities willing to be invested across every sampled nation.

Furthermore, a number of caveats apply to the data collection and CE. The analysis assumes that respondents understood and internalized the investment options (choice objects A, B, C) shown to them. Especially with regard to the setup of 'profit rate' and 'holding period', this may not have been the case, as respondents may not have fully understood the interplay of these two factors. While the CE was designed this way to simplify the math of a multi-year investment, it may still be a source of bias in the data collection. However, no related issues were found during the CE pre-test, which took place only in developed nations of Italy, Norway, and Austria.

It is also important to acknowledge the effects that a hypothetical bias may have in respondents' manifested choices according to potential deviations from actual investment behaviours when confronted with a similar investment proposition in a real-life situation. This might lead to an over-estimation of the social potentials of each MS, and therefore inaccurately depict the real level of interest and willingness to invest of the average individual respondent.

In an attempt to account for the effect of hypothetical bias in the CE, the survey asked respondents if they would like to share their email to receive information on actual investment options from companies that offer CRE investments. This exercise exposed respondents to a small real-world 'cost' of sifting through future emails, and served to measure the sincerity of their interest in the CRE investments options. Almost half (48%) of CE participants explicitly stated their interest in receiving such information periodically and allowed access to their email addresses. Although the high proportion of respondents sharing their email suggests a sincere interest in real-world CRE schemes, some responses that were at odds with stated choice behaviour. In particular, 1963 respondents who chose to invest in all eight choice tasks but then did not give their email for follow-up; and 697 respondents who chose not to invest in all choice tasks but then gave their email. These two groups of respondents were considered to be candidates for hypothetical bias. As a robustness check, all 2660 respondents were dropped from the sample followed by a re-run of the SBSS procedure detailed in section 3.1. The full results of this exercise are not reported for brevity (available upon request), but the final EU-28 social potential is estimated at €151 billion when the potentially biased responses are removed. This is a 14% decrease from the original €176 billion estimated in Table 4, yet would still represent a substantial contribution for financing next decade's €340 billion required investment in RES capacity.

5. Discussion

It is important to note that the experimental design of the research presented herein assumes that all citizens have access to market information and community investment options provided by reliable institutions. Most notably, it guarantees a risk-free investment operationalised through a trustworthy and straightforward financial vehicle. These facts, along with the availability of multiple investment options, offers a plausible explanation for the substantial social potential and high acceptance rates expressed for the investments. Therefore, the results outlined above substantiate the need to ensure that easily accessible, trustworthy, and risk-insured community investment options are available across EU MSs to unlock their social potentials for investing in CRE. This section presents policy-relevant insights that would help move towards a risk-minimised regulatory environment for citizen-led RE finance and thus help satisfy the main policy recommendation that flows from our empirical analysis.

In addition, the details of a 'plausibility check' stemming from the analytical results are further disclosed in the Supplementary Materials. This exploratory exercise employs aggregate figures on national wind power capacities and wind-based electricity generation from European countries to translate the estimated social potential of citizen-financed wind CRE initiatives into approximate installed wind power capacity estimates, and GHG abatement potentials. The results at the conclusion of this procedure indicate that realizing the social potential from citizen-led investments in wind-based CRE implies a deployment of 91 GW of installed wind power capacity, the generation of up to 197 TWh of renewable energy annually across Europe, and an average increase of 8.3% in final renewable energy consumption across EU Member States. This would lead to the abatement of over 103 MtCO2eq annually and result in a 2.4% annual reduction in greenhouse gas emissions from 2018 levels. These figures suggest a plausible impact stemming from the roll-out of wind-based CRE schemes across the EU-28. On a more critical note, while wind CRE options may be a significant lever for realizing a citizen-driven renewable energy system, these should be seen as only one of many other needed measures to successfully realize a timely transition towards carbon-neutrality by 2050.

5.1. The effect of RE subsidies on the estimated social potential

In line with previous research on the role of financial participation in the social acceptance of RE [28–37], the findings presented in this research suggest a tangible relationship between financial participation and co-ownership, and increased acceptance for localised forms of RE generation from European citizens.

It is important to highlight that the empirical analysis presented in the main results estimates the EU's social potential for collectively investing in community-administered wind farm cooperatives *under current market conditions* – that is, without capital subsidies or any other national support mechanism for RE development such as feed-in policies, investment/production tax credits, or other fiscal incentives. The results therefore reflect a conservative estimation of a *subsidy-free* social potential. However, national support schemes to RE generation are commonly employed throughout the EU-28. In order to understand the potential of subsidy schemes to influence citizens' willingness to co-invest in a community-administered wind farm development, we perform a scenario analysis using the SBSS process outlined in section 3. This analysis also constitutes a sensitivity analysis of the effect of profit rate assumptions on the estimated social potential, as discussed in section 4.4 above.

In order to do so, for each sampled country we take the values derived from the national RE support schemes reported in Ref. [75] (expressed in millions of EUR) and use these to re-calculate the profit rates for wind energy generation following the step-wise procedure outlined in section 3.1 (see Table A3 in Supplementary Materials for detailed figures).

In particular, for each sampled country, the amount of public financial support provided to RE generation in 2016[12] is divided by the corresponding national renewable power capacity installed in 2017. The resulting values depict the amount of public financial support (in Euros) obtained for every MW of existing renewable power capacity in every sampled country. This figure is then summed to the values obtained in step 4 of the outlined profit rate procedure (that is, the avg. annual revenue obtained from the generation and sale of energy per GW of

[12] To the authors knowledge, the values obtained from Ref. [75] offer the most recent available figures for all EU Member States *aggregated*.

installed wind power capacity) in order to obtain a proxy of the added revenue derived from the provision of public financial support to RE generation in every country sampled.

We then re-conduct the SBSS analytical procedure as outlined in section 3.1.2 to assess the changes in each country's representative respondent's probability of accepting the most-preferred investment option incorporating a *subsidised* profit rate for their investment, and quantify the resulting social potential stemming from those probability changes (see Table A4 in Supplementary Materials for details).

The results at the conclusion of this analytical procedure indicate that a *subsidised* social potential would yield a 27% increase in the expected volume of citizen investments collected across the EU, and reach a total volume of €224 billion (Fig. 2). This equates to 1.3% of the EU's GDP in 2018. Thus, our social simulation results suggest that subsidies can play a role in increasing the total volume of CRE wind capacity realized. Though this result is still subject to the caveat discussed above, namely that citizens have access to, and awareness of, CRE investment options, policy strategies to make this a reality are discussed in the following sub-sections.

5.2. Regulatory risk, market instability and investor confidence

One possible reason for the high levels of interest observed in the CE may be the low-risk, stable framing of the investment options. As such, unlocking the EU's social potential may require a stable regulatory framework that facilitates market access and a level playing field for new market participants. Unstable regulatory frameworks imposing retroactive modifications to previously approved policies and RE support schemes would likely increase regulatory risk and reduce the market acceptance for RE investments. Similarly, uncertain revenue projections stemming from volatile electricity prices and fully exposed investments to market risk would substantially challenge the business case for local scale RE development and likely reduce investor appetite for CRE. Both regulatory and market risks would violate the conditions

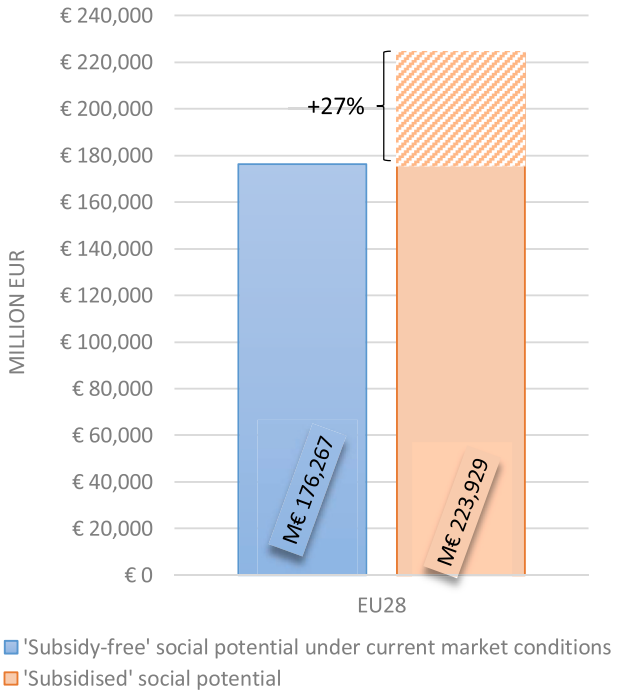


Fig. 2. EU-wide estimated social potentials for funding CRE wind generation under current market conditions (subsidy-free) and with added 2016 national subsidies to support community renewable energy.
Source: Own elaboration based on CE data and [75].

of the choice experiment and add significant uncertainty to the investment, which has been shown to reduce participation in the case of household RE adoption [76].

Appropriate revenue mechanisms may therefore prove a critical element in creating a risk-contained environment for citizen-led finance in CRE. In that respect, the results from this study substantiate the case for tailoring national RE support mechanisms according to the specific cost structures and unique financial, material and operational capabilities of a more diverse set of market participants involving less-experienced CRE entities, along with more traditional, larger RE developers. The EU's current climate and energy regulatory framework, NECPs and related set of RE support mechanisms do not address this need successfully [2,3,5,75] and, as such, undermine the ability of European citizens to partake in CRE schemes and co-benefit from Europe's low-carbon energy transition.

5.3. Citizen agency in the energy transition

These insights attempt to contextualize this research into the ongoing transformation that energy markets must undergo for accommodating the transition to a low-carbon energy system with an increasingly diverse set of actors. In that respect, the idea of *social potential* developed through this research may serve as a useful conceptual tool to further explore how the Energy Union's regulatory framework can be operationalised for supporting more inclusive and participatory pathways towards a decarbonised energy future. Collective finance for alternative energy generation schemes shaped by collaborative dynamics around local communities offers a vehicle of collective action leading to such citizen empowerment and the development of shared agency.

Extending the availability and awareness of CRE investment options could be a potentially resourceful approach in promoting the uptake of CRE schemes throughout Europe. Specifically, the provision of easily accessible, trustworthy, and low-risk community investment options and revenue mechanisms may be a viable means to expedite the pace of RES deployment and increase citizen participation through community-based forms of energy generation. The extent of citizenry empowerment and collective agency derived from €176 billion in potential CRE investment may prove a pivotal element for redefining Europe's Energy Union from a political commitment to a citizen endeavour where "citizens take ownership of the energy transition, benefit from new technologies [and] participate actively in the market" [7, p. 2].

6. Conclusion

This study quantifies the social potential for participating in CRE investments to assess the ability of citizen-driven financing to bridge the next decade's investment gap for a decarbonised energy system. Using responses obtained from an international survey and choice experiment across the EU-28, a novel Survey-Based Social Simulation quantification method is developed and illustrated. The method relies on estimating the probability that the average representative citizen in each nation would participate in a CRE scheme with optimal investment and operational characteristics. These probabilities are imputed using a discrete choice model anchored in economic random utility theory.

The results obtained indicate a substantial social potential of €176 billion that could be harnessed from European citizens willing to co-finance community-administered wind energy cooperatives with market-based rates of return. Realizing this social potential would be enough to halve the investment requirements foreseen to achieve a 32% RES share by 2030, leading to an aggregated energy generation potential of 195,805 GWh every year.

In light of the substantial interest and potential for participation in CRE initiatives, EU energy and climate policy must strive to generate trustworthy financial vehicles, stable regulation, and low-risk market conditions. Such a climate would facilitate the incorporation of more

innovative yet risk exposed CRE developers (e.g. energy cooperatives) and help to expedite the increased penetration of RE in the EU.

Author contribution statement

Cristian Pons-Seres de Brauwer: Conceptualisation, Writing - Original Draft, Formal Analysis, Visualisation, Writing - Review & Editing. **Jed J. Cohen:** Conceptualisation, Methodology, Formal Analysis, Validation, Writing - Review & Editing.

Data availability

The full dataset used for the analysis reported in this study is available at https://doi.org/10.5281/zenodo.3524917. The analysis code can be made available upon request.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2020.110300.

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