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The post COVID-19 green recovery in practice: Assessing the profitability of a policy proposal on residential photovoltaic plants

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ABSTRACT

The development of photovoltaic (PV) energy has been very significant in the last years, thanks to cost reductions brought about by policy actions favouring the transition from a fossil to a green society. As this transition is likely to stretch over the long term, policy support must be programmed accordingly. In light of the human and economic shock effected by COVID-19, the Italian government has offered a tax deduction of 110% over 5 years for the realization of new PV residential plants. We propose to integrate this tool with the application of a bonus for energy produced and self-consumed, in order to support the development of decentralized systems. In this paper, we provide an economic assessment of a 3 kW plant in the context of several policy scenarios. The results underline the great opportunity for consumers to tackle climate change whilst obtaining relevant economic profits. The study can be replicated on a global scale.

1. Introduction

In cities, 75% of carbon dioxide emissions stem from energy use (Bai et al., 2018) and several policy actions are requested for reducing the overall emission abatement costs of cities favouring sustainable economic growth (Ji and Zhou, 2020). The realization of renewable plants is needed to produce green energy, and thereby reduce climate change and increase energy security (Cheng et al., 2020; Meng et al., 2019). The need of an equitable sharing of the economic impacts of global warming policy has since long been ascertain in the literature (Rose, 1990), however some policy makers have opted to not consider the climate change as a global issue. Moreover, although several governments provided incentive tools for the production of electricity from renewable energy sources (RES), policy schemes are often characterized by mutual interactions, that could lead to conflicts or synergies (del Río, 2014). In this picture, it is certainly relevant to balance various policy instruments to maximize policy synergic effects (Kwon, 2018).

The 2030 climate and energy framework identifies a binding renewable energy target for the European Union (EU) for 2030 of at least 32% of final energy consumption and the European Green Deal sets an ambitious roadmap for making the EU's economy sustainable. The EU could become climate neutral by 2050; to reach this goal all economy sectors should partecipate to the effort. Indeed a key role will be played by the decarbonisation of the energy sector and the renovation of buildings, helping people reducing energy cost bills and energy consumption. The European green energy system should be characterized by a fully-fledged internal energy market based on the cooperation of all Member States in energy production and by the presence of institutional procedures oriented to maintain external energy security (Baumann and Simmerl, 2011).

Recently, the production of photovoltaic (PV) energy has significantly increased; some estimates (elaborated by the International Renewable Energy Agency - IRENA) identify that solar PV power capacity reached 586 GW atn the end of 2019, with the largest contributions from China (205 GW), Japan (61.8 GW), the USA (60.5 GW), Germany (49 GW), India (34.8 GW) and Italy (20.9 GW) - (IRENA, 2020). At present, the sector also provides a significant number of jobs (3.6 million at the end of 2018) (IRENA, 2019a). Subsidies have played a key role in facilitating the transition towards a low-carbon society (He et al., 2018); in particular, the feed-in-tariff (FIT) scheme has supported the development of PV markets by reducing the associated costs (Corwin and Johnson, 2019; Lacal Arantegui and Jäger-Waldau, 2018). Technological improvements have favoured the reduction of PV energy cost

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Nomenclature

A_{cell}	Active surface
b^{u}_{inc}	Unitary bonus (incentive)
BEP	Break-even point
BES	Battery energy storage
C_{ae}	Administrative/electrical connection cost
C_{lcs}	Loan capital share cost
C_{inv}	Investment cost
$C_{inv,\ unit}$	Unitary investment cost
dE_f	Decreased efficiency of a system
DCI	Discounted cash inflow
DCO	Discounted cash outflow
E_{Out}	Energy output of the system
EoL	End of Life
EU	European Union
FER	Renewable Energy Source
FIT	Feed-in-tariff
inf	Rate of inflation
inf_{el}	Rate of energy inflation
IRENA	International Renewable Energy Agency
k_f	Optimum angle of tilt
LCOE	Levelized cost of energy
N	Lifetime of a PV system
N_{debt}	Period of loan
N_{TaxD}	Period of tax deduction
η_{bos}	Balance of system efficiency
η_f	Number of PV modules to be installed
η_m	Module efficiency
NPV	Net present value
p^c	Electricity purchase price
p^s	Electricity selling price
P_{Cass}	Percentage of assurance cost
P_{Ci}	Percentage of inverter cost
P_{Cm}	Percentage of maintenance cost
P_{Ctax}	Percentage of taxes cost
P_f	Nominal power of a PV module
PV	Photovoltaic
r	Opportunity cost of capital
r_d	Interest rate on a loan
RES	Renewable Energy Source
t	Period time
t_r	Average annual insolation
S	Plant size
SP_{el}	Sale of energy
$TaxD_u$	Unitary tax deduction
$\omega_{self,c}$	Percentage of energy self-consumption
Vat	Value added tax

(Ding et al., 2020). In 2018, the levelized cost of energy (LCOE) of utility-scale solar was $0.085 USD/kWh (compared to $0.371 USD/kWh in 2010). The lowest LCOE was registered in India ($0.06 USD/kWh), followed by China, Italy and United States. Instead, Japan and United Kingdom had a LCOE of $0.156 USD/kWh (IRENA, 2019b). These ongoing cost and performance improvements in silicon solar cells have driven significant growth in the sector (Green, 2016). Furthermore, the reduced costs have enabled PV to become competitive, and many cities are able to achieve – without subsidies – PV electricity prices lower than those supplied by the grid. However, this benefit has only been verified in some cases (Yan et al., 2019). In particular, some authors have underlined that large-scale solar energy projects may only recover the initial investment when the financial costs are low (Apostoleris et al., 2019). Other analyses have underlined that fossil fuel subsidies can negatively influence the competitiveness of renewable energy technologies (Schmidt et al., 2012).

While there have been numerous economic analyses of PV plants in the literature, attention should turn now to new solutions to support their development. Low profitability presents a challenge to the realization of new PV systems (Mah et al., 2018), and profits in mature markets depend mainly on the share of self-consumption (Chiaroni et al., 2014; López Prol and Steininger, 2017; McKenna et al., 2018; Reis et al., 2019). In fact, avoided energy costs are typically more profitable than the produced electricity, itself. The development of decentralized systems is dependent on the local production of energy (Kalkbrenner, 2019; Khan, 2020; Rathore et al., 2019). To this end, it is necessary to improve consumer habits, as this is a pre-condition for optimizing the size of battery energy storage (BES) system (Cucchiella et al., 2016). Battery systems do not automatically reduce emission levels or energy consumption, unless doing so directly facilitates the production of green energy (Fares and Webber, 2017). Furthermore, the development of decentralized systems requires new network tariffs from regulatory bodies (Azarova et al., 2018). Recently, COVID-19 has determined a significant socio-economic shock, and each affected country is now seeking to stimulate the economy with new initiatives. The COVID-19 pandemic has determined a wide decline in oil consumption as a result of the recessions in the global manufacturing activities. In addition, the domestic electricity consumption increased underlying as the security of energy supply will require the development of distributed energy storage infrastructure with a pivotal role played by artificial intelligence technologies (Wang et al., 2020). The total value of carbon footprint was considerably reduced due to electricity consumption in the lockdown phase, with a special role played by solar photovoltaic in the Italian context (one of the most affected countries worldwide by the COVID-19 outbreak) (Rugani and Caro, 2020). The green economy, which incorporates solar energy, is an economic vision that supports the environment. For this reason, the Italian government has announced an eco-bonus in the form of a tax deduction of 110% over 5 years. The present work will support policy-makers assessing the economic impact of residential PV systems by proposing several policy scenarios, including a new bonus for the amount of energy produced and self-consumed. None of the proposed scenarios requires additional public funds. Furthermore, these policy proposals – and their relative economic values – can be applied on a global scale.

2. Policy proposal

The economic assessment of a project is highly dependent on the input data. Furthermore, the final assessment may modify the perception of stakeholders, particularly in the context of policy-making (Kazhamiaka et al., 2017; Ramírez et al., 2017). In particular, a misalignment between government and local communities can generate a gap determined by the acceptance of renewables at societal level and its disapproval at local level. REN21 identifies three dimensions of social acceptance of renewable energy: i) socio-political, ii) market and iii) community (REN21, 2020). Only the alignment of these three dimensions would guarantee full social acceptance.

Over recent years, the Italian PV market has presented low growth in the number of installed PV plants. The European Commission has approved Decree FER1 (equivalent to RES), aimed at supporting the production of electricity from renewables in Italy. D.M. July 04, 2019 subdivides plants into four groups; the realization of new PV plants is present in two of them:

- Group A, which also includes on-shore wind plants; and

- Group A-2, in which PV plants are realized in substitution of asbestos.

There are two ways of accessing incentives relating to PV plants:

- Applying to the register of plants with power greater than 1 kW (20 kW for PV) and less than 1 MW, belonging to groups A and A-2.
- Applying to auction procedures referring to plants with power greater than or equal to 1 MW, belonging to group A.

There are seven calls for applications (register or auction procedures). The results of the first call (not influenced by Covid-19) are presented in Table 1.

Incentives are paid according to the net electricity fed into the grid (70–105 €/MWh, as a function of plant size), for a period of 20 years. Additionally, a potential bonus of 10 €/MWh is provided when energy is also self-consumed (referring to plants built on rooftops with a capacity of up to 100 kW and a self-consumed energy share exceeding 40%).

The results of the first of seven calls (without considering the effect of COVID-19) underlined a gap of approximately 92 MW of the total unassigned 800 MW. The policy proposal presented here is the first to use the amount of uninstalled power from the first two calls (with the second influenced negatively by COVID-19) to promote the development of PV plants with less than 20 kW of power in the residential sector. The proposal will give PV plants the same treatment as other renewable resources (e.g. on-shore wind and hydro plants) and will thereby support the increase in green power to achieve key targets. The proposal does not require additional public funds, but makes use of budgeted money that will otherwise go unused within the FER1. The development of decentralized systems requires the production of local energy and the substitution of green electricity for fossil fuels, in order to tackle climate change (Kalkbrenner, 2019; Khan, 2020; Rathore et al., 2019). The present proposal extends the FER1 bonus for the amount of energy produced and self-consumed to also include the residential sector; this will be compatible with the subsidized tax deduction. The period of the bonus can be fixed to either 10 years (the period provided for the subsidized tax deduction) or 20 years (the assumed lifetime of a PV plant). The value of the bonus can be determined by stakeholders, via a cooperative approach. For the example analyses, we define a minimum value of 10 €/MWh (as provided for medium and large plants within FER1) and two greater values of 25 €/MWh and 40 €/MWh, respectively.

In previous years, the subsidized tax deduction was fixed at 50%, instead of the baseline value of 36%. However, in May 2020, the Italian government released a "Revival Decree" (Decree Law 34/2020) to respond to the economic crisis caused by COVID-19. Decree Law 34/2020 introduced a new percentage of deduction, for a total of 110%, linked to interventions that favour energy savings. In particular, the following three measures were identified: replacement of air conditioning systems in single-family buildings or in the common parts of buildings and thermal insulation through materials which respect the minimum environmental criteria. Within this decree, an eco-bonus measure provides an increased subsidized tax deduction of 110% (was fixed to 50% before of this Decree) for the realization of new PV plants. The deduction is divided into five equal yearly amounts. It is estimated that the reduction in tax revenue will be compensated by the increased volume of economic activities in the building sector and, consequently, will increase business turnover of all firms involved, and thereby not alter the equilibrium of public accounts. This assumption has been embraced by the Italian Government. In addition, energy not directly consumed is transferred free of charge to the grid. The decree also allows for interventions to be carried out by individuals and condominiums and two distinct business scenarios are proposed:

- PV2400 scenario, in which the tax deduction of 110% is applied to the entire investment fixed to 2400 €/kW when it is associated to green operations such as thermal insolation or air conditioning.
- PV1600 scenario, in which the tax deduction of 110% is applied to the entire investment fixed to 1600 €/kW when it is not associated to green operations.

This initiative is not compatible with other public incentives. We think that a combination of the measure proposed by the government and the proposal we present here will best support the development of decentralized systems in which consumers are pushed to synchronize their energy consumption with solar production peaks.

3. Materials and methods

3.1. Economic model

The discounted cash flow (DCF) methodology, which considers the time value of money, is widely used in both academic and industrial contexts (Yan et al., 2019). DCF is used to estimate the profitability of a project considering only cash inflows and outflows. The determination of the cash flows is based on the incremental approach and their aggregation during the lifetime of the project is realized thanks to the use of an appropriate capital opportunity cost (Courtney et al., 1997). Net present value (NPV) is a common indicator used to measure the quantity of money generated by the realization of a green project (Dong and Sigrin, 2019; Keen and Apt, 2019). NPV considers all cash flows over the lifetime of a project at a discounted rate of return. The DCF mathematical model was initially presented by (D'Adamo, 2018; D'Adamo et al., 2020b), but for the present study, it was modified following changes introduced by the policy proposals.

The model included four potential cash inflows:

- avoided energy costs, represented by the electricity purchase price for an investor (i.e. negative cost, interpreted as a revenue);
- sale of energy (i.e. energy not self-consumed).
- subsidies for the amount of energy produced and self-consumed, represented by the value of the bonus; and
- tax deductions, evaluated in their subsidized forms.

Investment costs represented the main cash outflows, and the replacement of the inverter during the 10th year was assumed. PV systems are typically characterized by a low operative cost.

$$NPV = DCI - DCO \tag{1}$$

$$DCI = \sum_{t=1}^{N} \left(\omega_{self,c} \times E_{Out,t} \times p_t^c + \left(1 - \omega_{self,c}\right) \times E_{Out,t} \times p_t^s + \omega_{self,c} \times E_{Out,t} \times b_{inc}^u\right) / (1+r)^t + \sum_{t=1}^{N_{TaxD}} \left(\left(C_{inv} / N_{TaxD}\right) \times TaxD_u\right) / (1+r)^t \tag{2}$$

Table 1
First call D.M. July 04, 2019.

	Group	i	ii	iii = f (ii)	iv = f (ii)	v = i - iv
		Power quota (MW)	Requests sent (MW)	Requests excluded (MW)	Requests satisfied (MW)	Delta power (MW)
Auction procedure	A	500	595.4	19.7	500	0
Register	A	45	92.3	17.9	45	0
	A-2	100	15.0	7.0	7.9	92.1

$$E_{Out,t} = t_r \times K_f \times \eta_m \times \eta_{bos} \times A_{cell} \times P_f \times \eta_f \quad (3)$$

$$E_{out,t+1} = E_{out,t} * (1 - dE_f) \quad (4)$$

$$p^c_{t+1} = p^c_t \times (1 + inf_{el}) \quad (5)$$

$$DCO = \sum_{t=0}^{N_{debt}-1} \left(C_{inv} / N_{debt} + (C_{inv} - C_{lcs,t}) \times r_d\right) / (1+r)^t + \sum_{t=1}^{N} \left(P_{Cm} \times C_{inv} \times (1+inf) + P_{Cass} \times C_{inv} \times (1+inf) + SP_{el,t} \times P_{Ctax}\right) / (1+r)^t + (P_{Ci} \times C_{inv}) / (1+r)^{10} + C_{ae} \quad (6)$$

$$C_{inv} = C_{inv,unit} \times (1 + Vat) \times P_f \times \eta_f \quad (7)$$

All simulations are conducted through the Excel programme in order to facilitate the replicability of results.

3.2. Input data

The present study aimed at evaluating the profitability of a PV residential plant in light of several policy scenarios. The following ten scenarios were examined:

- a subsidized tax deduction of 50% over 10 years (prior to the current eco-bonus);
- a subsidized tax deduction of 110% over 5 years (the current eco-bonus within the Revival Decree) applied to both PV2400 and PV1600 business scenarios;
- a bonus for produced and self-consumed energy (new proposal) at a value of 10, 25 or 40 €/MWh over a period of 10 years (more conservative than 20 years), with a fixed tax deduction of 50% over 10 years (to define the impact of the proposal without challenging the tax deduction); and
- a bonus of 10 or 40 €/MWh (with no intermediate values analyzed) associated with the tax deduction of 110% over 5 years in both PV2400 and PV1600 business scenarios. It is worth underlining that these four alternative scenarios presented the challenge of two critical variables.

Table 2
Economic inputs (Cerino Abdin and Noussan, 2018; Chiacchio et al., 2019; D'Adamo, 2018; Luthander et al., 2016; Ramli et al., 2015; Talavera et al., 2019).

Variable	Value	Variable	Value
A_{cell}	7 m^2/kWp	P_{Cass}	0.4%
b^u_{inc}	10-25-40 €/MWh	P_{Ci}	15%
C_{ae}	250 €	P_{Cm}	1%
$C_{inv,\ unit}$	1900 €/kW	P_{Ctax}	40%
dE_f	0.7%	p_f	function of S
Inf	2%	p^s	0-6 cent€/kWh
inf_{el}	1.5%	R	5%
k_f	1.13	r_d	3%
N	20 years	S	3 kW
N_{debt}	10 years	t_r	1450 kWh/m^2 × y
N_{TaxD}	5–10 years	$TaxD_u$	36%-50%–110%
η_{bos}	85%	Vat	10%
η_f	function of S	$w_{self,c}$	0%-10%-20%-30%-40%-50%-60%-70%-80%-90%–100%
η_m	16%		
p^c	19 cent€/kWh		

All scenarios were evaluated as a function of the share of self-consumed energy varying from 0% (all energy sold) to 100% (all energy self-consumed). In this work, the unitary investment cost for PV plants was assumed equal to 1900 €/kW. Within PV2400 scenario, we applied a unitary tax deduction of 110% to the entire investment. Within PV1600 scenario, we applied a unitary tax deduction of 110% only for a part of initial investment (equal to 1600 €/kW), while a percentage of 36% was applied to the remaining share (equal to 300 €/kW). Table 2 presents the model input data, in which investment costs are covered by third party funds. The typical size of a residential plant was assumed to be 3 kW. The lifetime of the PV project was fixed to 20 years (Ramli et al., 2015) and the cost opportunity of capital was assumed equal to 5% (D'Adamo et al., 2020b). Plant was realized in a territory with a medium level of insolation (1450 kWh/m^2 × y) and the energy produced during the first year was equal to 4680 kWh.

4. Results

4.1. Baseline scenario

The present work analyzed the profitability of a residential PV plant in a developed and subsidized market. Fig. 1 shows the economic results of 110 case studies, which were obtained by combining the 10 policy scenarios with 11 consumer habits. Findings of this work showed a LCOE equal to 0.09 €/kWh in a residential configuration that is not far from the value proposed in section 1 referred to the utility-scale solar.

The analysis of baseline scenarios underlined that profitability was not verified in 27 cases, in which the share of energy self-consumed was lower than 30% when tax deduction was fixed at 50% with bonus or when was assumed equal to 110% considering PV1600 scenario. Instead, NPV was positive for a share lower than 20% when the tax deduction was assumed equal to 110% evaluating PV2400 scenario. Generally, it was possible to define the break-even point (BEP) in terms of the share of self-consumed energy: it varied from 26 to 29% when the bonus was applied and was equal to 30% when no bonus was offered analysing the 50% tax deduction scenario. Instead, considering the 110% tax deduction scenario we observed the following ranges of BEP: 19–22% for PV1600 scenario and 12–14% for PV2400 scenario. Maximum economic profit equalled 2143 €/kW in the 50% tax

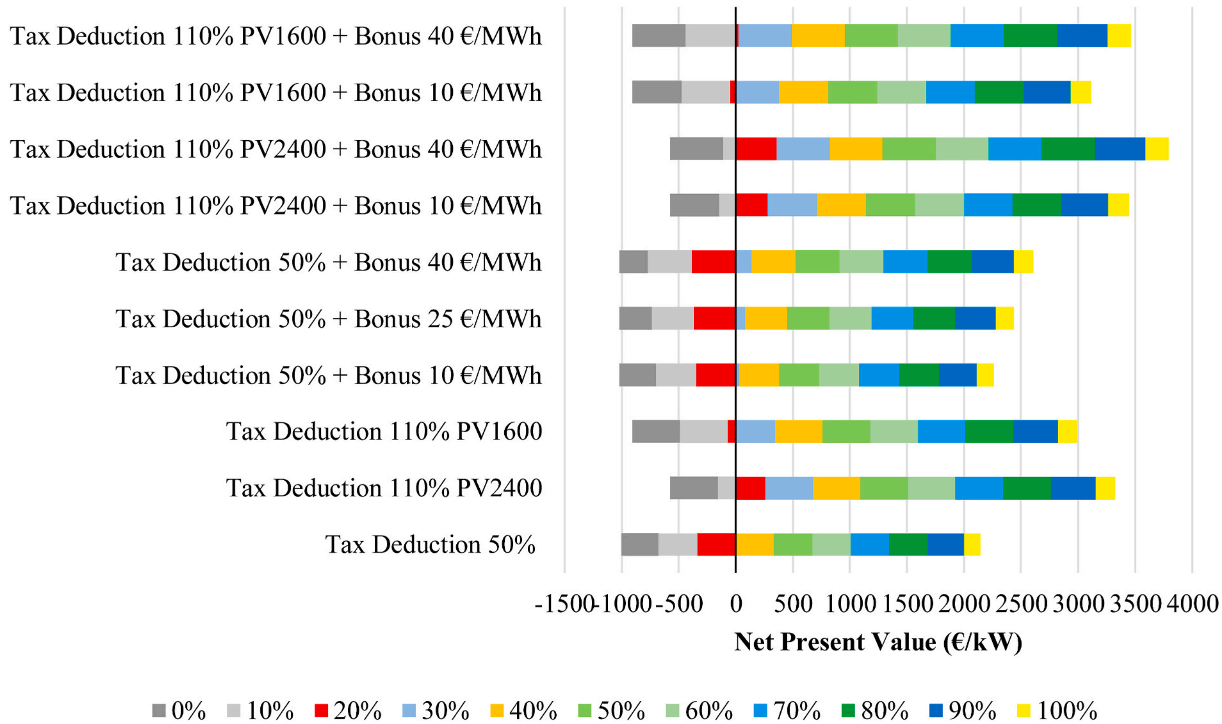

Fig. 1. NPV (expressed in €/kW) for a 3 kW PV plant calculated as a function of the share of self-consumed energy. This variable played a key role in the economic evaluation. Profitability was verified in all scenarios characterized by a good harmonisation between demanded and produced energy.

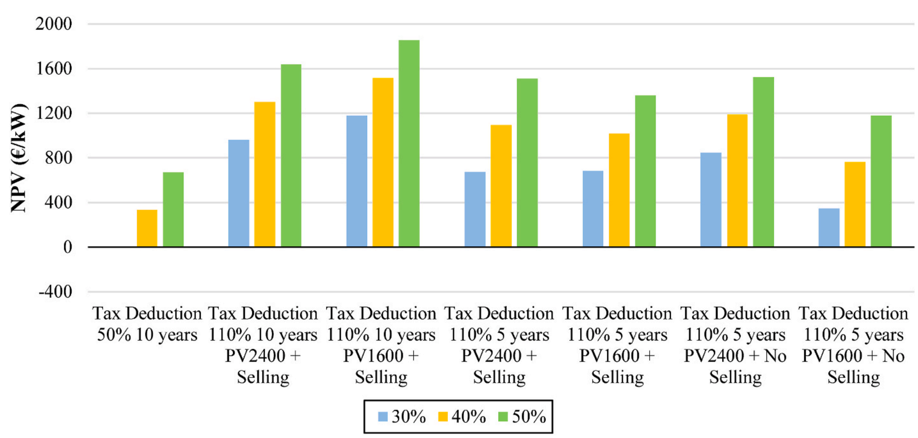

Fig. 2. NPV (expressed in €/kW) for a 3 kW PV plant in function of three variables: percentage tax deduction, period of tax deduction and selling price of energy.

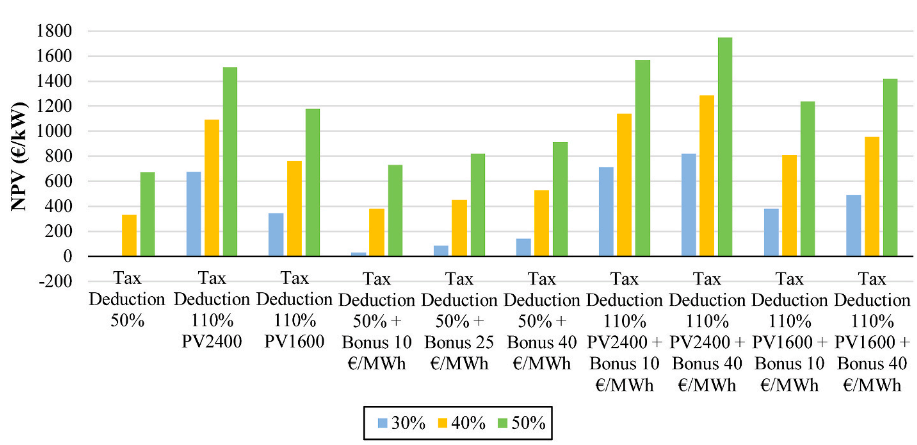

Fig. 3. NPV (expressed in €/kW) for a 3 kW PV plant, indicating profitability in almost all scenarios, ranging from 30 to 1750 €/kW.

deduction scenario. All other scenarios presented an increased NPV: 2260–2609 €/kW in scenarios with a bonus for self-consumed energy or 2996–3327 €/kW in scenarios with a 110% tax deduction. The combination of both policy proposals determined a maximum NPV varying from 3113 to 3793 €/kW.

These values could also be obtained when all energy was self-consumed, but the literature proposes that, more commonly, shares of self-consumption are 30%, 40% and 50% (D'Adamo, 2018; Fett et al., 2019; Lang et al., 2016; Luthander et al., 2016). For this reason, we focused on these three shares of self-consumed energy in our model. Furthermore, the introduction of the Revival Decree has determined three significant changes to the economic model: i) percentage tax deduction from 50% to 110%; ii) period of deduction from 10 to 5 years and iii) selling price becomes null. We have separated each variation evaluating relative scenarios. In fact, these three variables play a key-role to compare policy action before eco-bonus and one associated to the application of this eco-bonus (Fig. 2 - Appendix 1).

Assuming that the selling price of energy does not vary, the introduction of the eco-bonus significantly changed the profitability of the PV plants, determining an increase in NPV of 1184 €/kW, of which 968 €/kW was associated with the different values of deduction, while the remainder (216 €/kW) was linked to the lower deduction period

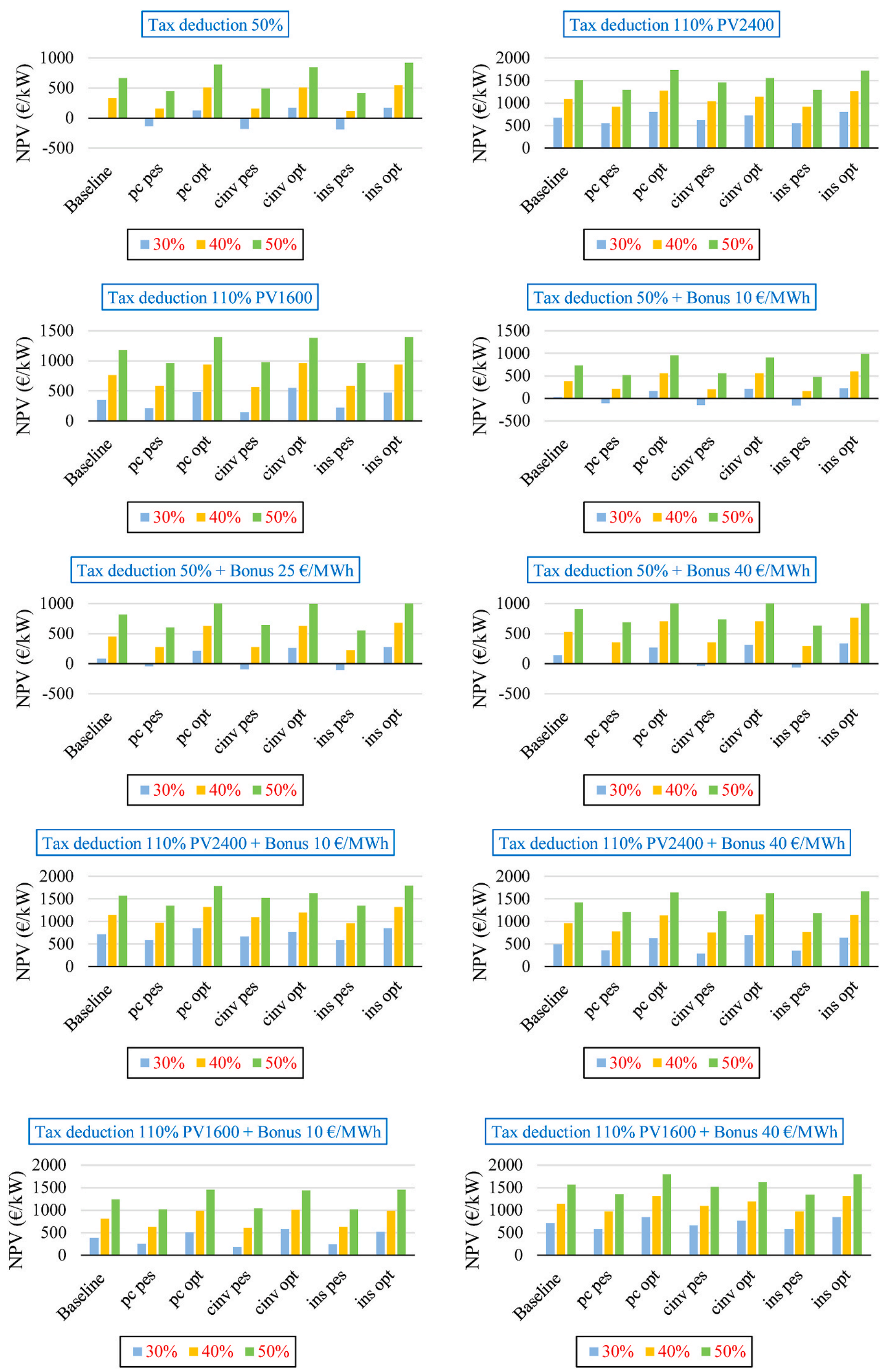

Fig. 4. NPV (expressed in €/kW) for a 3 kW PV plant, calculated for baseline and alternative scenarios. The sensitivity and scenario analyses provided solidity to the results. The following acronyms are used: pes (pessimistic), opt (optimistic), pc (purchase cost), cinv (investment cost), ins (insolation level).

regarding PV2400 scenario. It was verified an increase in NPV also for PV1600 scenario, but numerically less significant: an overall variation of 853 €/kW, of which 688 €/kW was associated with the percentage of tax deduction, while 165 €/kW was linked to the period of deduction. Considering that the energy produced and not-self consumed was conferred to the grid without revenues, we registered a reduction of the PV plants. It varied from 739 €/kW (share equal to 0%) to 33 €/kW (share equal to 90%). Is it more relevant to have a tax deduction over 5 years or a tax deduction over 10 years with a selling price defined by the market? Results of this work underlined a reduction in profits for those consumers that are not able to reach a share of self-consumed energy equal or above 70%. In fact, tax deduction over 10 years with selling price fixed to 60 €/MWh has NPV equal to 2343 €/kW, which is slightly higher (2314 €/kW) than the one calculated for the tax deduction over 5 years analyzing PV2400 scenario with the share of self-consumption equal to 70% (see Table A1). The same is verified considering PV1600 scenario (2430 €/kW vs 2372 €/kW - Table A2) but having the share of self-consumption equal to 80%.

These results underline that the overall increase of NPV associated with the eco-bonus (corresponding to an increase of tax deductibility from 50% to 110%), ranged from 682 €/kW to 839 €/kW in the PV2400 scenario and from 351 €/kW to 509 €/kW in the PV1600 scenario (the interval corresponding to a level of self consumption varying from 30% to 50%) - (Fig. 3).

The introduction of the bonus for self-consumed energy had less of an impact than the eco-bonus. NPV increased by 36 €/kW when the share of self-consumption was 30% and a bonus of 10 €/MWh was applied, while it increased 145 €/kW with a bonus of 40 €/MWh. Instead, when the share of self-consumption was equal to 50%, the increase in NPV varied from 60 to 241 €/kW. Thus, only one case achieved a value greater than 216 €/kW. Is it more relevant to have a tax deduction over 5 years or a tax deduction over 5 years with a bonus for self-consumed energy at a value varying from 10 to 40 €/MWh? Are these policy proposals compatible? What is the advantage of this combination of policies? The combination of a subsidized tax deduction of 110% over a period of 5 years and a 10 or 40 €/MWh bonus for self-consumed energy presented a NPV ranging from 712 to 1750 €/kW for PV2400 scenario and from 381 to 1420 €/kW for PV1600 scenario. These values are in line with the values proposed in previous research applying a FIT scheme: 715–915 €/kW (Chiaroni et al., 2014), 1805–2385 €/kW (Campoccia et al., 2014) and (−1300)–3300 €/kW (Bortolini et al., 2013).

Results of this work underline that a 10% increase in self-consumed energy determined an increase in NPV of 338 €/kW in the scenario before eco-bonus. The different value of tax deduction was able to change this value, determining an increase of 417 €/kW. Finally the application of a bonus for self-consumed energy with the tax deduction fixed to 110% implied an increase of 350 €/kW or 386 €/kW, for a bonus of 10 €/MWh or 40 €/MWh, respectively.

4.2. Alternative scenarios

Sensitivity analysis shows the variation in NPV when a single variable is modified and the scenario analysis showed the variation in NPV when more variables were changed. In the present analysis, the share of self-consumption was a critical variable that had already been analyzed by previous research. According to literature (Choudhary and Srivastava, 2019; Coria et al., 2019; D'Adamo, 2018; López Prol and Steininger, 2017), the following parameters were selected:

- Purchase price of electricity (p^c) increased/decreased by 2 cent€/kWh. The optimistic scenario had a value of 21 cent€/kWh, while the pessimistic scenario was equal to 17 cent€/kWh.
- Unitary investment cost ($C_{inv,\ unit}$) increased/decreased by 200 €/kW. The optimistic scenario presented a value of 1700 €/kW, while the pessimistic scenario was equal to 2100 €/kW.
- Level of insolation (t_r) increased/decreased by 150 kWh/m^2 × y. The optimistic scenario considered a value of 1600 kWh/m^2 × y, while the pessimistic scenario presented 1300 kWh/m^2 × y.

A total of 660 alternative scenarios were obtained by combining the 6 alternative changes in critical variables with the 110 case studies associated with the baseline scenarios. Fig. 4 shows the profit per unit of power installed (NPV/kW) associated with the three values of the share of self-consumed energy previously proposed (30%, 40% and 50%). Absolute values for all case studies in which the share of self-consumed energy varied from 0% to 100% are presented in Appendix 2.

Assessment of the baseline and alternative scenarios showed that approximately 71% of the case studies presented a positive NPV. Profitability was mainly verified when the subsidized tax deduction was assumed equal to 110%. BEP varied from 11% to 15% considering the PV2400 scenario, while greater values were registered for the PV1600 scenario (varying from 15% to 20% in the optimistic scenarios and from 22% to 27% in pessimistic scenarios). Alternatively, when the tax deduction was assumed equal to 50%, the profitability of a PV plant with a 30% share of energy self-consumed was verified only when a bonus of 40 €/MWh was applied, in the context of the pessimistic scenarios (when purchase price of electricity was fixed to 17 cent€/kWh). However, BEP varied from 25% to 27% also without the eco-bonus in the optimistic scenarios.

While an increase in the cost of the energy bill may be seen as a negative for consumers who do not have access to a PV plant, it increases the likelihood that investors will make green choices. In the present analyses, an increase of 2 cent€/kWh implied a greater NPV (of 132 €/kW) when the share of self-consumed energy was 30%. This increase was more significant (176 and 219 €/kW) when the share was 40% and 50%, respectively. There was no variation as a function of the policy proposal. With respect to investment costs, a variation of 200 €/kW determined a NPV varying from 52 to 200 €/kW as a function of the maximum eligible expenditure (2400 or 1600 €/kW, respectively), with the tax deduction equal to 110%. This result suggests that a more generous tax deduction may reduce variation in the economic performance of PV plants; in fact, NPV varied by 176 €/kW when the tax deduction was equal to 50% (36% was applied to the remaining share of investment when the limit was fixed to 1600 €/kW). Finally, variation in the level of insolation depended on the location in which the PV plant was installed. It was not influenced by the value of the tax deduction, but changed as a function of the share of self-consumed energy. For a percentage of 30%, NPV varied 181 €/kW, while for shares of 40% and 50%, it varied 216 €/kW and 251 €/kW, respectively. This was verified for a level of insolation that increased/decreased by 150 kWh/m^2 × y considering tax deduction of 50%. The introduction of the bonus determined greater variation: 4–6 €/kW or 15–25 €/kW for a bonus of 10 or 40 €/kW, respectively. In addition, both PV2400 and PV1600 scenarios were characterized by a lower reduction in the NPV (varying from 129 to 216 €/kW) when increasing tax deductibility from 50% to 110%; however, this was solely due to the change in the sale price.

5. Conclusion and policy implications

In January 2020 a previously unknown virus, at the time named SARS-CoV-2, was identified in China. A few weeks later, an outbreak, later defined by the WHO as pandemic, put to test the health care systems of both advanced and developing countries. Lockdown measures had to be enforced in order to slow down the spread and mortality of the infectious disease. As of April 23, 2020, around one third of global population was subject to lockdown due to the COVID-19 outbreak.

As a result, people have been forced to stay at home and business (except essential ones) to shut down. As a consequence of this unprecedented measure, a symmetric shock to both demand and supply occurred, with dramatic consequences for the world economy.

The International Monetary Fund (2020), in its outlook named "the Great Lockdown", forecasts a sharp contraction of global economy – around −3% – that is much worse than the one observed during the 2008–9 financial crisis. Along with this dramatic economic crisis, the COVID-19 pandemic clearly showed "the lack of resilience in supply chains and the impact that disruptions may have on a global network scale as individual supply chain connections and nodes fail" (Golan et al., 2020); a phenomenon which has brought to the attention of researchers, analysts and policy makers the need to push national economies to be more self-sufficient and rely more on short supply chains in order to enhance systemic resilience.

In this framework, there is the potential to stimulate a synergic and converging effort to address both the COVID-19 pandemic crisis (health, social) and needed green transition (economic, technology, legal, environmental), pushing the policy forward to realize an incredible effort to provide future opportunities for the new generations. If probably only a vaccine can alt the spread of COVID-19, at systemic level this period has underlined the urgent need to reconcile the concepts of resilience and sustainability (Elmqvist et al., 2019).

The European Commission has approved Decree FER1 in order to reach future ambitious goals. Although the 2030 climate and energy framework and European Green Deal have different timeframes, they are both oriented to decarbonize the energy sector and to transform the building sector through not only the substitution of fossil fuels with green energy but also by increasing consumers responsibility.

Consequently, the energy system will play a pivotal role in driving European countries towards the aimed for green recovery. Indeed, the transition from a fossil to a green society is a global challenge that requires a new vision. While some policy-makers believe that climate change is not a real issue, COVID-19 has shown us that our planet requires more respect, and energy question is one place where this respect can begin. This is particularly relevant considering that this pandemic period has no end date and energy systems should be transformed requiring new energy policy needs. Investment, financing and other policy tools should be used to support this energy transition (Brown et al., 2020). This work follows this line of thinking, measuring the economic impacts associated to a new policy action with the aim to support consumers' energy choices. Indeed, a survey on solar system policy showed that lack of subsidies was a barrier to solar PV installation (Setyawati, 2020), while subsidies released through a FIT scheme played a key-role in supporting the development of PV markets (Lacal Arantegui and Jäger-Waldau, 2018; Pyrgou et al., 2016), stimulating technological improvements and significant reduction in energy costs (Honrubia-Escribano et al., 2018; Martin and Rice, 2018). In this way, new energy policy incentives can be thought to support the ambitious programme of the new European Green Deal that aims at making Europe the first climate-neutral continent by 2050 (Cambini et al., 2020). The role of tax deduction linked to PV investments was investigated in the literature (Lazzeroni et al., 2020; Magnani et al., 2020) and consumers, who pay to use electricity after the installation of a PV system, are seen as investors, but also producers of energy (the so-called prosumers). The diffusion of prosumer communities would determine a significant change for electric utilities implicated in this transition from centralized to decentralized systems (Zapata Riveros et al., 2019), making the system overall more flexible and resilient.

Literature has identified that subsidies played a key-role to develop PV systems, however they cannot be proposed as a perpetual assistance. Indeed, additional policy schemes should be considered and the value of subsidies should be properly ascertain. This work evaluates the economic impact of several policies on residential PV systems, underlying that the eco-bonus scheme is characterized by three significant assumptions: the first concerns the subsidized tax deduction fixed at 110%, the second regards the period of tax deduction fixed at 5 years, and the third concerns the presence of an eligible spending ceiling. In the hypothesis that the consumer has no fiscal capacity, there is the possibility to transfer the deduction to third parties or to the same PV system installation firm, obtaining a discount on the price to be paid. The eco-bonus initiative is challenging, but the tax deduction of 110% over 5 years can reduce or prevent altogether energy bill costs and generate additional 17–38 € (or 9–29 €) of profits every 2 months for 20 years in PV2400 (or PV1600) scenarios. This holds true for a 3 kW plant, and if consumers are able to achieve synchronization higher than 30–50%, their profits will be even greater. Revival Decree is oriented to increase the green power installed, but it is not fit to increase consumers' responsibility. Our proposal implies that citizens are called to play a key-role in the transition towards green cities. Likewise, by synchronizing production and consumption of energy additional economic profits can be generated. Furthermore, the introduction of a bonus for energy produced and self-consumed can generate additional 4–6 € of profits every 2 months if the bonus is set to 40 €/MWh. While this measure has a lower economic impact than tax deduction, it nonetheless presents some strengths. At base, it supports the development of a decentralized system, increasing the self-sufficiency of the energy system. Additionally, it might attract new investors, and additional green power can be installed by recovering power that is not currently used within the FER1. Furthermore, the proposal can make use of public funds that are currently available and not used within the FER1. In a period of economic crisis, such sustainable measures are desirable. Furthermore, the same initiative can be adopted in other contexts, e.g. public offices (D'Adamo et al., 2020b) and agricultural activities (Cossu et al., 2020). A bonus could be applied also for plants greater than 100 kW, when it is realized without speculative effects but oriented only to maximize the green production in function of the availability of rooftops (D'Adamo et al., 2020a). We therefore suggest that policy-makers implement three bonus values, as a function of the plant size: for example 40 €/MWh for plants from 1 to 20 kW, 25 €/MWh for plants from 20 to 100 kW and 10 €/MWh for plants from 100 kW to 500 kW (or 1 MW). The adoption of a bonus requires a legislative change in which this additional policy tool is made compatible with the tax deduction provided by Revival Decree. In fact, these policy measures show synergy and convergence. At the same time, it is requested not to create bureaucratic complications between national and local actors, providing supports to citizens to understand the sustainable potential associated with this integrated policy actions – hence minimizing the 'do nothing' costs.

Results confirm that the profitability of PV plants depends on the share of self-consumed energy, and that the adoption of the proposed policy can influence their economic performance. This work underlines how subsidies should not be seen as perpetual assistance, but rather as positive externalities that reduce emissions levels translating environmental improvements into economic gains. For this reason, the installation of BES systems will be fundamental within decentralized configurations, but the definition of its size should consider the impact of the entire life cycle of a product (including End of Life (EoL) phase). Consumers can be oriented to maximize synchronization between demanded and produced energy, reaching additional profits and the remaining share of energy that is not possible self-consumed can be used by BES system optimizing the sustainable goal. Future directions of research will measure the impact of subsidized initiatives provided for

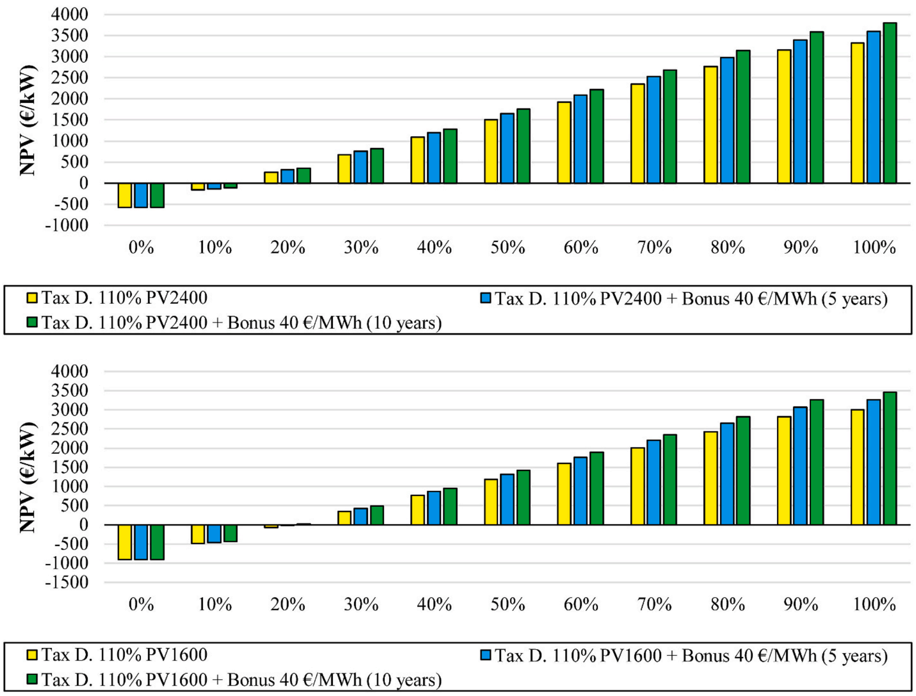

Fig. 5. NPV (expressed in €/kW) for a 3 kW PV plant, calculated for several scenarios based on tax deduction (Tax D.) fixed equal to 110%. The difference among three scenarios is represented by the presence of the bonus fixed equal to 40 €/MWh in both scenarios in which it is provided for 10 and 5 years or if it is not provided.

battery systems within the Italian Revival Decree.

Furthermore, an alternative economic source of financing the proposed policy measure could be represented by the Next Generation EU recovery plan, considering that this proposal is aimed at the creation of a sustainable and green Europe. This extra effort would allow increasing significantly the number of plants that could be installed. For instance, considering a typical residential plant of 3 kW with 1560 kWh as energy produced by 1 kW plant, we will have about 2340 kWh suitable to receive a bonus considering the share of self-consumption fixed to 50%. In this way, each plant will require 94 €/year fixing the value of bonus to 40 €/MWh (0.04 €/kWh). By multiplying 94 €/year for the number of plants (that can be defined as a function of number consumers or as a function of installed power) we can get an estimate of the required funds. Additionally, it is necessary to define the period over which this bonus is provided – having in mind the timeframe of the Next Generation EU recovery plan, a period of 5 years can be assumed. In this case the profitability of the PV plant will change; however, Fig. 5 shows how the key results obtained in the previous analysis are substantially confirmed. In this case, the introduction of a bonus for energy produced and self-consumed can generate additional 2–3 € of profits every 2 months if the bonus is set to 40 €/MWh (Appendix 3).

The proposed policy can be replicated in other territories, and the values presented in this work can represent a point of reference. From an economic perspective, the tax deduction reduces the impact of investment costs, while the bonus promotes an increase in the percentage of energy produced and self-consumed. Finally, consumers can now understand both baseline and alternative scenarios in which PV plants generate economic returns with low risk, while providing vital support to counteract climate change. In this way, citizens can be part of the radical green transformation of urban and rural living places. In addition, the eco-bonus favours the green transition of the electricity sector through the development of small local plants, while the bonus for the self-consumed energy increases the responsibility of individuals towards their energy consumption models.

CRediT authorship contribution statement

Idiano D'Adamo: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Massimo Gastaldi:** Supervision, Writing - original draft, Writing - review & editing. **Piergiuseppe Morone:** Supervision, Writing - original draft, Writing - review & editing.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2020.111910.

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