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Summary

The European Union has set ambitious targets for emission reduction and the penetration of renewable energy, including the electricity generation sector as one of the major emitters of CO2. After a period of subsidy-driven investments, the costs of renewables decreased strongly making investments more attractive. Since European countries differ strongly in terms of natural resources, we analyse the profitability of wind onshore and offshore and solar PV across Europe to determine where it is optimal to invest in the future and to understand which factors drive the profitability of the investments. We use a power systems model to simulate the whole European electricity market in 2030. Using the renewable revenues determined by the model, we calculate the internal rate of return to analyse how profitable each technology is in each country. We find that investments in the considered technologies are not homogeneously profitable across Europe. This suggests that cooperation between European countries can be expected to achieve the overall targets at lower costs than nationally-driven approaches. We also find that in many countries, wind onshore and solar PV are profitable by 2030 in absence of any financial support. Wind offshore does not seem to be profitable without financial support.

Keywords: Renewable Energy Targets, Renewable Electricity Generation, RES-E Target, EU Electricity Market, Profitability

JEL Classification: Q4, Q42

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Are renewables profitable in 2030? A comparison between wind and solar across Europe

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Abstract

The European Union has set ambitious targets for emission reduction and the penetration of renewable energy, including the electricity generation sector as one of the major emitters of CO_2. After a period of subsidy-driven investments, the costs of renewables decreased strongly making investments more attractive. Since European countries differ strongly in terms of natural resources, we analyse the profitability of wind onshore and offshore and solar PV across Europe to determine where it is optimal to invest in the future and to understand which factors drive the profitability of the investments. We use a power systems model to simulate the whole European electricity market in 2030. Using the renewable revenues determined by the model, we calculate the internal rate of return to analyse how profitable each technology is in each country. We find that investments in the considered technologies are not homogeneously profitable across Europe. This suggests that cooperation between European countries can be expected to achieve the overall targets at lower costs than nationally-driven approaches. We also find that in many countries, wind onshore and solar PV are profitable by 2030 in absence of any financial support. Wind offshore does not seem to be profitable without financial support.

Keywords: Renewable energy targets, renewable electricity generation, RES-E target, EU electricity market, profitability
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1 Introduction

The European Commission (EC) and the European Council set ambitious energy targets for 2030 in order to secure clean and efficient energy in the European Union.[1] In 2014, EU countries agreed that by 2030, the share of renewables should be 27% of total energy consumption in order to achieve the overall target of 40% GHG emission reduction (Commission, 2014a). In 2018, this overall renewable target has been increased to 32% of total energy consumption (Commission, 2018). This target holds at the EU level, so all countries should work together either by reducing the energy demand or increasing generation from renewable energy sources (RES), to achieve the overall goals.

Electricity generation is one of the sectors affected by the EU targets together with transport, agriculture and industry, as it is one of the major sectors responsible for total emissions (EUROSTAT, 2017). Following the track started with the 2020 targets on emission reductions, renewable electricity generation (RES-E) should increase to 49% of total electricity demand by 2030 in order to be consistent with the overall target on total energy demand, as noted by the Commission (2014a) in its own impact assessment analysis.

The installed capacity in renewable energy has increased strongly during the last decade, when every EU country set up different incentives to promote the investment in renewable generation. There are several works that focus on the costs and the regulatory changes needed to promote the investments in renewable energy. All these works highlight that subsidies given to renewables are positively related with the investment in this type of generation in all EU countries. Papaefthymiou and Dragoon (2016) and Held et al. (2018) analyse the impact of increasing RES-E penetration in the EU system and focus on the associated distribution network costs. Other studies (Edenhofer et al., 2013; Cambini and Rondi, 2010; Boomsma et al., 2012; Sisodia and Soares, 2015; Winkler et al., 2016) analyse how regulation and subsidies are necessary to encourage the investment in renewable energy.

Despite the positive correlation between subsidies and investment in RES-E, it is widely recognised that the use of subsidies is suboptimal with respect to the first best solution of carbon-pricing (Kalkuhl et al., 2013), so a rigorous analysis is needed to assess under which conditions investments in renewable energy are economically profitable without subsidies.

Looking at 2030, investment costs associated with renewables should decrease over time, making the investment in renewable energy more attractive to market operators

[1]See EC Directive 2009/28, Commission (2014b) and EU Council (2014).

(IRENA, 2012). However, European countries are quite different in terms of natural resources and the availability of wind and solar irradiation, thus a careful analysis of the profitability of investments in renewable technologies is required to determine where it is optimal to invest in the future, as capital costs of renewables are often higher than for fossil fuels (Neuhoff et al., 2016).

Despite the importance of the subject, there are not many studies focusing on the profitability of renewable technologies in 2030 or beyond, in particular when it comes to comparing countries across Europe. Duscha et al. (2016) combined short and long term simulations to find the optimal technological and economical pattern to meet the emission targets up to 2050. The authors examine the impact of different RES targets on the EU economy and find that the Commission's overall renewable energy target should be a minimum target rather than the maximum level of RES. The authors show that a RES penetration going beyond the overall EU target results in higher economic benefits for the Union. As the investment costs of RES decrease over time, the authors highlight that new investments rely on convenient cost of capital, and the regulation should then focus on reducing that in the next years. Finally, the authors point out that offshore wind and tidal energy are not economically efficient, so subsidies would need to be provided in order to incentivise investments in these technologies. Safarzyńska and van den Bergh (2017) focus on the financial stability associated with the investment in renewables and find that investments in gas fired plants instead of renewable technologies would be beneficial in countries in which coal plants are still active and play a major role in generation. Finally Knopf et al. (2015) find that the cost-effective share of RES-E to meet the European targets in 2030 ranges from 43% to 56%, raising the question about the profitability of new investments above the threshold of 49% identified by the Commission. However, no specific focus is given to the profitability of specific technologies.

In this work we therefore investigate whether the investment in specific renewable technologies (solar, wind onshore and wind offshore) is profitable across Europe. In particular, we compare several scenarios to determine under which conditions investment in renewables would be profitable in each country without additional financial support. A review of methods adopted to optimally locate investments in renewables is provided by Tan et al. (2013). We use a power systems model to simulate the whole European electricity market in 2030 aimed at investigating the costs and benefits of investment in renewable technologies for all EU countries. We then use the output of the power systems model to calculate the internal rate of return for solar, wind onshore and wind offshore investments in each country in Europe. We focus on these technologies in this paper because significant investments in additional hydro capacity are rather unlikely and limitations to the feedstock potential are found to limit the expansion of biomass for electricity only generation (Hennig et al., 2016).

The remainder of this paper is organised as follows. Section 2 describes the methodology and data used. Section 3 presents our results, which we discuss in section 4. Section 5 concludes.

2 Methodology and data

2.1 Methodology

We use the Artelys Crystal Super Grid power systems model to simulate the European electricity market in 2030 (EU28 plus Switzerland and Norway).[2] The model minimises the overall generation costs across the EU to meet demand at an hourly resolution and subject to generator technical characteristics.

In these simulations a competitive market is assumed across the EU (i.e. no market power and power plants bid their short run marginal cost) and we assume perfect foresight, whereby the model has full knowledge of all input variables such as demand and variable renewable generation output. This hypothesis does not allow us to investigate the potential beneficial effects of competition in mitigating anti-competitive behaviour in different markets, as noted by Neuhoff et al. (2005). The resulting market price is calculated as the marginal price at member state level and does not include any extra revenues from potential balancing, reserve or capacity markets or costs such as grid infrastructure cost, capital costs or taxes.

For the economic assessment, we calculate the internal rate of return (IRR) for solar PV, wind onshore and wind offshore at member state level. We deliberately chose to calculate the IRR rather than the net present value (NPV) or the annuity since the calculation of the latter always requires an interest rate as input. Consequently, an NPV or annuity can only be interpreted subject to the assumed interest rate (Bertsch et al., 2017a). We acknowledge that the use of the NPV or annuity would be more common than the use of the IRR within a single company with a fixed equity ratio (and hence a quasi

[2] See: `https://www.artelys.com`. We thank Artelys for the provision of the software and their support.

fixed interest rate). However, since equity ratios may differ between investors and interest rates for borrowed capital may differ between countries, we deemed the IRR to be more appropriate for comparing the profitability of investments across Europe.

The IRR is the interest rate that leads to an NPV or annuity of €0 including the cash flows CF_t (revenues and expenses, including investments CF_0) over all time periods $t \in \{0, ..., T\}$ of an investment project, where T is the project's lifetime (see equation (1)). Artelys calculates annual revenues based on the hourly generation by technology and country and hourly prices by country assuming marginal costs of zero for the considered technologies. Capital and fixed operational expenditures are considered ex post and, together with the revenues calculated by Artelys, provide input to our IRR calculations.

$$NPV = \sum_{t=0}^{T} \frac{1}{(1 + IRR)^t} CF_t \equiv 0 \tag{1}$$

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2.2 Data

The input data for our analysis can be structured into three main categories: *a)* supply and demand data for modelling the European power system, *b)* fuel and carbon prices, and *c)* capital and fixed operational expenditures of the considered RES-E technologies.

a) Supply and demand data

The supply and demand input data to Artelys are broadly based on Deane et al. (2017). This includes data on the generation portfolio and demand for the 28 European member states from the 2016 European Commission modelling of a Reference Scenario (PRIMES) of the future European Energy system.[3] The Reference Scenario is one vision of the European power system in 2030 based on business-as-usual assumptions, including full implementation of European climate and energy policies adopted by December 2014 to achieve a renewable electricity penetration of 49% in 2030 up from 27.5% in 2014.[4] [5]

[3]PRIMES is a partial equilibrium model that provides projections of detailed energy balances, both for demand and supply, CO_2 emissions, investment in demand and supply, energy technology penetration, prices and costs". The projections are set up in order to meet the EU 2016 targets on emissions for 2030:`http://ec.europa.eu/environment/archives/air/models/primes.htm`.

[4]The generation mixes of Switzerland and Norway are not included in the PRIMES scenario. Swiss data was developed based on data available from the Federal Department of the Environment, Transport, Energy and Communications (DETEC). Norwegian data was developed based on data available from the Norwegian government (see: `https://www.regjeringen.no`) for thermal power plants and the Norwegian water resources and energy directorate (NVE, see: `https://www.nve.no`) for renewables including hydro power.

[5]Note that the portfolio used for PRIMES 2016 does not exactly match the recent EU target to achieve 32% of renewables in final energy consumption by 2030 (see: `http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm`). It is consistent, however, with a 49% target for renewable electricity.

In addition to the data of the PRIMES Reference Scenario, hourly wind power generation for each Member State was taken from Aparicio et al. (2016). Hourly solar profiles for each Member State were developed using NREL's PVWatts® Calculator web application, which determines the electricity production of photovoltaic systems based on system location and basic system design parameters. Moreover, our model includes the network interconnection capacities between EU countries, as described in ENTSOE (2016) for 2030.

Table 1: Installed RES capacity, MW, by country, 2030

Country	Wind Onshore	Wind Offshore	Solar	Hydro	Other Renewables
AT	4,545	0	2,821	13,756	815
BE	3,557	3,350	3,818	1,484	820
BG	2,122	0	2,572	2,338	101
CH	834	0	5,272	16,587	0
CY	229	0	529	0	11
CZ	488	0	2,391	1,109	274
DE	57,796	9,418	63,959	13,102	7,065
DK	4,134	2,318	838	10	2,870
EE	445	0	1	8	154
ES	29,824	64	24,564	16,795	1,923
FI	2,763	152	19	3,461	3,330
FR	23,717	7,055	25,382	28,803	4,350
GR	6,038	0	5,616	3,579	232
HR	682	0	686	2,190	29
HU	477	0	106	57	409
IE	4,003	131	19	587	208
IT	15,574	3	24,562	18,939	6,182
LT	467	0	74	116	139
LU	302	0	131	1,345	35
LV	238	48	2	1,589	108
MT	0	0	198	0	2
NI	1,525	500	4	0	133
NL	6,975	3,121	5,586	37	2,308
NO	1,000	0	15	30,495	155
PL	9,442	897	99	1,039	2,105
PT	6,275	28	2,172	9,971	693
RO	6,017	0	2,223	6,645	157
SE	9,013	0	88	16,742	3,161
SI	242	0	779	1,284	118
SK	19	0	680	1,725	332
UK	18,550	12,846	11,040	4,624	17,233
Total	217,292	39,930	186,243	198,416	55,451

The installed RES capacities by country are taken from PRIMES and summarised in Table 1. In this paper, RES capacities include hydro and thermal RES, where the latter is the sum of biomass, geothermal and other renewables. Table 1 reveals that the installed renewable capacity is not distributed homogeneously across Europe. Countries in the South, such as Spain and Portugal, have a higher proportion of solar generation than countries like Belgium or Ireland. Northern countries are rich in wind generation, and Central European countries have a variable proportion of both resources.

b) Fuel and carbon prices

The fuel prices used in our analysis are taken from DECC (2016) and summarised in Table 2. The generators' costs are based on fuel costs, emission costs and heat rates.[6]

Table 2: Fuel price assumptions, (€2010)

€/GJ	Nuclear	Coal	Gas (CCGT, OCGT, derived gas)	Oil	**Carbon**
Low	2.00	2.40	5.70	10.00	20.00
Baseline	2.00	2.90	8.50	14.80	37.00
High	2.00	3.70	12.30	21.50	40.00

Data source: DECC (2016). Exchange rate €/GBP=0.858

c) RES capital and fixed operational expenditures

As in Slednev et al. (2018), capital and fixed operational expenditures are taken from Taylor et al. (2016). For 2015, their assumptions are 1,810 US$/kW for solar PV, 1,560 US$/kW for wind onshore and 4,650 US$/kW for wind offshore translating into 1,629 €/kW for solar PV, 1,404 €/kW for wind onshore and 4,185 €/kW for wind offshore assuming an exchange rate of 1 US$= 0.90 €. For 2025, Taylor et al. (2016) assume technology costs of 790 US$/kW for solar PV, 1,370 US$/kW for wind onshore and 3,950 US$/kW for wind offshore translating into 711 €/kW for solar PV, 1,233 €/kW for wind onshore and 3,555 €/kW for wind offshore. Given that our study focusses on 2030, we will use the assumptions for 2025 as baseline technology costs. However, we will also carry out the analysis using the values for 2015 to show what happens if technology costs do not decrease as anticipated. Moreover, these assumptions will be varied in a number of additional sensitivity analyses the results of which are presented in section 3.4. In terms of fixed operating and maintenance costs, we assume 1% of the specific investment costs per year for solar PV and 2% for wind onshore and wind offshore. The lifetime of the investment is assumed to be 20 years for all considered technologies. Again, we will vary this assumption (see section 3.5) to explore the impact of longer/shorter lifetimes.

[6] Production costs for power plant type i, inclusive of CO_2, are calculated as:

$$ProdCost_i = FuelPrice_i * HeatRate_i + ETS * (HeatRate_i * CO_2EmissRate_i) \quad (2)$$

The assumed CO_2 emission rates are 93.6 kg/GJ for coal, 55.9 kg/GJ for gas and 77 kg/GJ for oil.

3 Results

We now present the results of our analysis. Section 3.1 provides an overview of the achieved RES-E shares by country and technology in 2030, whereas section 3.2 provides insights into the different technologies' profitability in each country. Subsequently, sections 3.3-3.5 illustrate the impact on the IRR when varying the assumptions in relation to fuel prices, technology costs and lifetime respectively.

3.1 RES-E shares

First, we calculate the renewable penetration using the model results. With our assumptions including the demand and generation portfolio from PRIMES, the share of renewable electricity generation (hydro, solar, wind, biomass and other renewables) is 49% of the total European electricity demand. This is in line with the recommendation by EU Commission Staff (2014) to meet the EU 2030 target in relation to total energy demand.

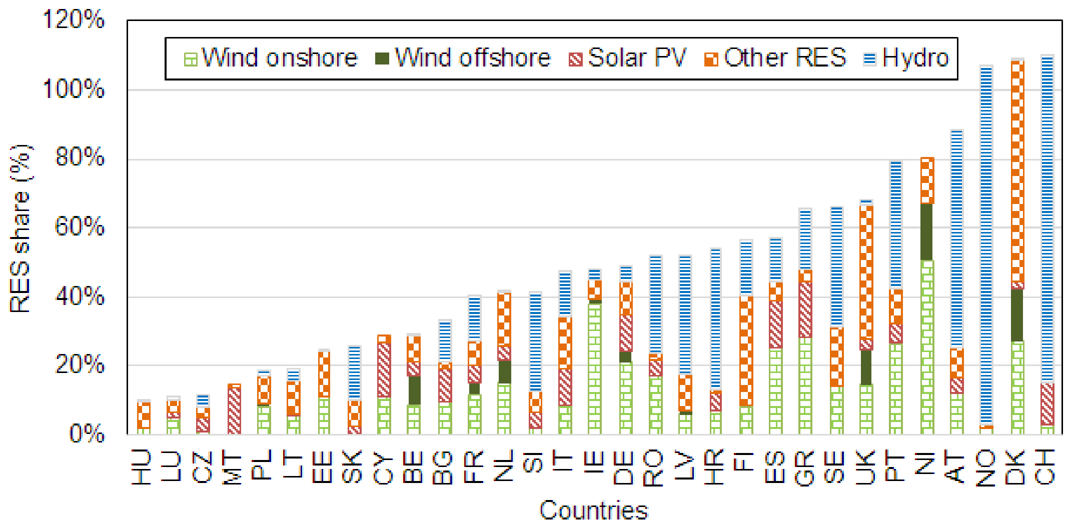


Figure 1: Proportion of RES generation on total demand, 2030

Figure 1 examines the proportion between RES-E generation and demand for each EU country (plus Switzerland and Norway). Figure 1 shows that Switzerland and countries in Scandinavia, e.g., Denmark and Norway, have the highest RES-E over demand proportion. These countries are followed by Austria (driven by their hydro power capacities, similar to Norway and Switzerland), the UK and a couple of Southern-European countries such as Portugal (79%), Greece (66%) and Spain (57%). Note that RES curtailment in our model is very low. In part, this can be explained by the fact that we do not consider the transmission network within each country. In addition, we assume that interconnection capacities between the countries have been realised accordingly to the 10 year network development plan (TYNDP) from ENTSOE. As a result, renewable generation may flow between the EU countries, reducing curtailment. Overall, the RES-E shares from our model should therefore be considered as upper limits. Eastern European countries have the lowest renewable share as a proportion of total demand. In countries such as Hungary, the Czech Republic, Poland and Lithuania less than 20% of final demand is met by renewable generation. Italy, Ireland and Germany have RES-E shares of almost 50%, whereas France has a relatively lower RES share of around 40%. On the other hand, however, France has a high share of nuclear generation, which is low-carbon, too.

Figure 1 also shows that countries with a very high overall RES-E share but without significant hydro capacities (e.g., Denmark and the UK) have rather high shares of other (thermal) RES-E. Moreover, it shows that with very few exceptions, the wind onshore shares are higher than the solar power shares. Overall, Figure 1 reveals that the expected RES shares in 2030 differ significantly across Europe. Because of differing RES-E capacity factors (mainly influenced by the geographical and meteorological conditions) and wholesale electricity market price levels and structures, we also expect the profitability of RES investments to differ strongly between countries. In the following subsections, we therefore analyse the profitability of RES according to the PRIMES model based on their economic performance in 2030 for each member state aimed at understanding which countries have favourable conditions for which technologies. Since significant investments in additional hydro capacity are rather unlikely and limitations to the feedstock potential may limit the expansion of biomass for electricity only generation (Hennig et al., 2016), we focus on investments in solar PV as well as wind onshore and wind offshore in our analysis.

3.2 Profitability of investment in RES-E

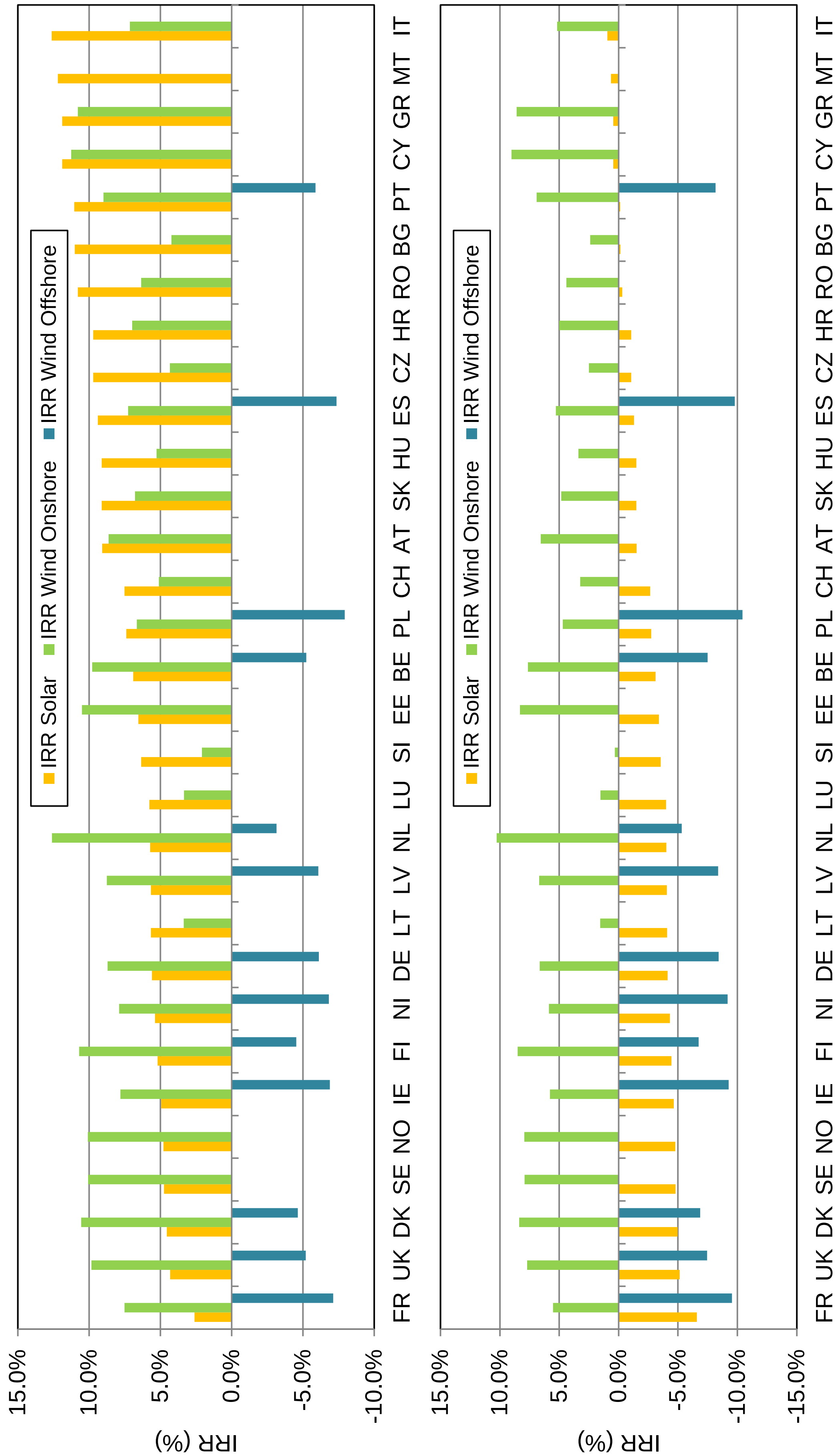
Figure 2a provides an overview of the profitability of the three considered RES-E technologies across Europe on the basis of the IRR. The IRR of the investments increases from the left to the right. For the baseline fuel price and technology cost assumptions, investment in wind onshore is more profitable than in solar PV for half of the countries, while solar PV is more profitable for the other half. Wind offshore is not profitable, neither considering high nor low capital costs.

Broadly speaking, four categories of countries can be identified. First, there are a number of countries (e.g., in Scandinavia and other parts of Northern or Western Europe) where wind onshore is rather profitable, whereas the profitability of solar PV is low. Second, there is a group of countries in the South-Eastern part of Central Europe where solar PV is rather profitable, whereas wind onshore investments reach their lowest IRRs (e.g., the Czech Republic, Slovakia, Hungary and Bulgaria). Third, there are some countries in Central Europe where the profitability of both solar PV and wind onshore is rather low (e.g., Luxembourg, Lithuania and Slovenia). Fourth, there are a few countries in Southern Europe with coastal access where the profitability of both technologies is rather high (e.g., Portugal, Greece and Cyprus).

Looking at the investment in solar power, Italy, with a large capacity of solar PV installed, has the highest profitability for this technology, followed by Malta, Greece, Cyprus and Portugal. Looking at the investment in wind onshore, the Netherlands, Cyprus and Greece achieve the highest IRRs, followed by a number of Scandinavian countries (Finland, Denmark, Sweden) and the UK. The situation is structurally similar for wind offshore investments. This technology achieves the relatively highest IRR in the Netherlands, followed by Finland, Denmark and the UK. However, for the baseline technology cost assumptions, this relatively highest IRR in the Netherlands is still negative.

As expected, Figure 2b generally shows that the profitability of RES-E investments is much lower if today's (2015) technology costs do not decrease as anticipated by Taylor et al. (2016). In this case, wind onshore investments are more profitable than solar PV investments for all considered countries. In other words, while the IRR of wind onshore investments only decreases by around 2%, there is a step change in terms of the profitability of solar PV investments. This is mainly driven by the much stronger cost reduction assumptions until 2025 in the case of solar PV as compared to wind onshore.

Overall, Figure 2 shows that investments in PV are particularly profitable in Southern European countries. Moreover, Figure 2 demonstrates the importance of reducing PV technology costs from today's levels in order to make this technology viable widely across Europe. Investments in wind onshore seem generally profitable in Northern European countries but also in some countries on the Mediterranean or Atlantic coast, the latter having favourable conditions for both solar PV and wind onshore. On the contrary, a number of countries in Central and Eastern Europe would neither have favourable conditions for PV nor wind. It might therefore be better for these countries to import renewable energy (certificates) from other EU countries with more favourable conditions assuming that the overall objective is to increase renewable penetration at the lowest-possible costs.



(a) *Baseline (2025 techn. costs)*

(b) *Today (2015 techn. costs)*

Figure 2: Overview of IRR across countries and technologies for today's and future technology cost assumptions

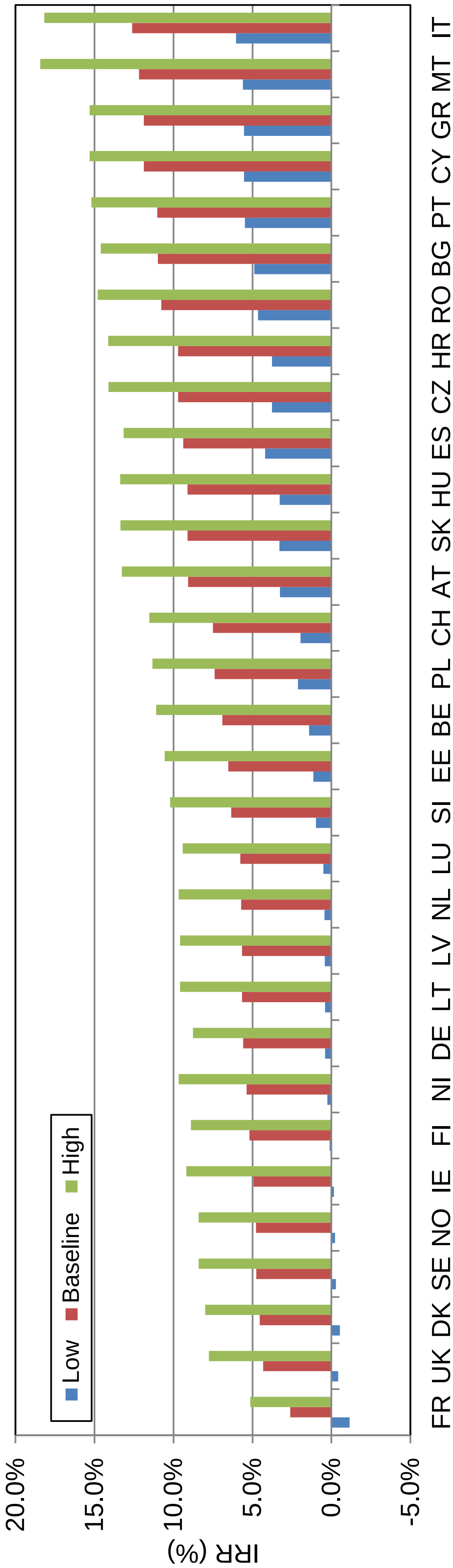
3.3 Impact of fuel price variations on the profitability of RES-E investments

Figures 3 and 4 show how the IRRs of the different RES-E investments change when fuel prices (and hence electricity prices) are higher or lower than the baseline assumptions (see Table 2 for the corresponding assumptions in the High and Low scenarios), while the technology costs are not changed. As expected, higher fuel prices increase the profitability of solar PV (see Figure 3a). Italy and Malta still achieve the highest IRRs for solar investments, now exceeding 18%. However, a number of countries in which the IRR was below 5% for the baseline assumptions now achieve an IRR of 8-9% (e.g., Scandinavia, the UK or Ireland). On average, the IRR increases by around 4% in the High fuel price scenario compared to the baseline fuel price scenario. In contrast, lower fuel prices result in IRRs around or below zero for solar investments for some countries (e.g., France, the UK, Ireland and Scandinavia). On average, the IRRs are around 5.5% lower in this scenario than for the baseline assumptions.

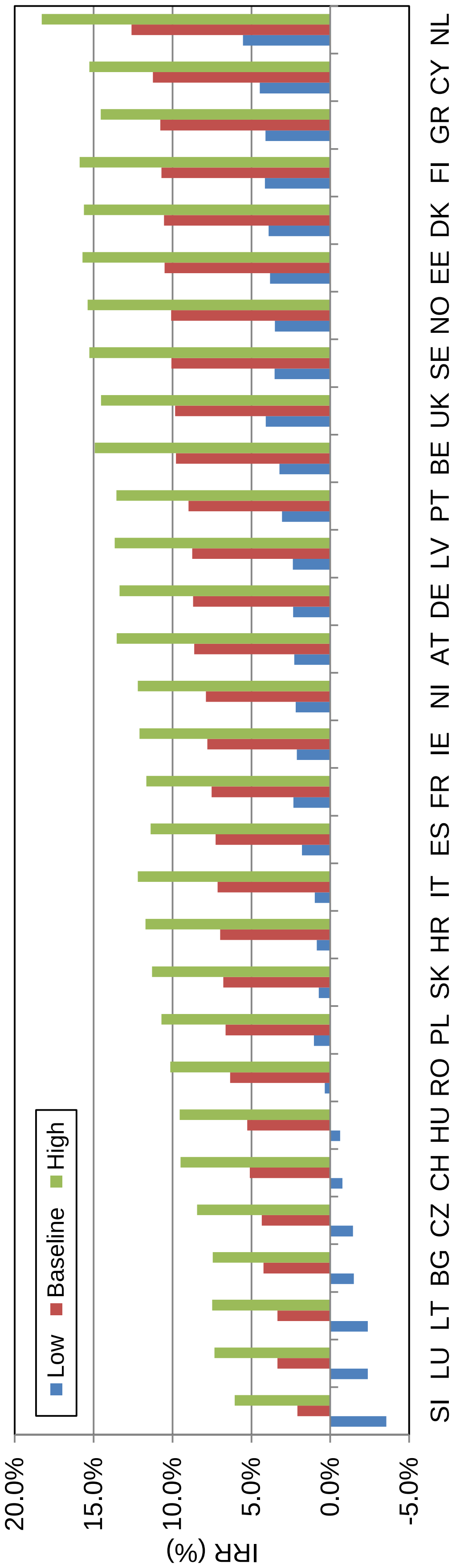
Figure 3b shows similar effects for wind onshore. On average, the IRRs are around 4.5% higher in the High fuel price scenario compared to the baseline scenario. Lower fuel prices result in IRRs that are around 6.1% lower on average than in the baseline scenario for this technology. This means that the IRRs for wind onshore investments are negative for some countries, including Slovenia, Luxembourg, Lithuania, Bulgaria and the Czech Republic, while Hungary and Romania yield IRRs of around zero under these fuel prices.

Figure 4 shows how wind offshore investments are affected by the different fuel price scenarios. In the scenario with high fuel prices, the IRRs are around 3.5% higher on average than under the baseline assumptions. While in the baseline scenario the IRRs for wind offshore were negative across Europe, the IRR is slighty positive under high fuel prices in the Netherlands (around 0.5%), followed by Finland and Denmark. Under low fuel prices, the IRRs of wind onshore would be strictly negative across Europe (around 6.4% lower on average than for the baseline assumptions), whereby the order between the countries remains largely unchanged.

Overall it is interesting to note that the fuel price variations do not have the exact same impact on all countries. For instance, Figure 3b shows that for wind onshore, the order between the countries would be slightly different under the High scenario than under the Baseline scenario. This can be explained by different power systems and generation portfolios, which are affected by the fuel price variations in different ways.



(a) *Solar PV*



(b) *Wind onshore*

Figure 3: Impact of fuel price variations on the IRR of solar and wind onshore investments across Europe, 2030

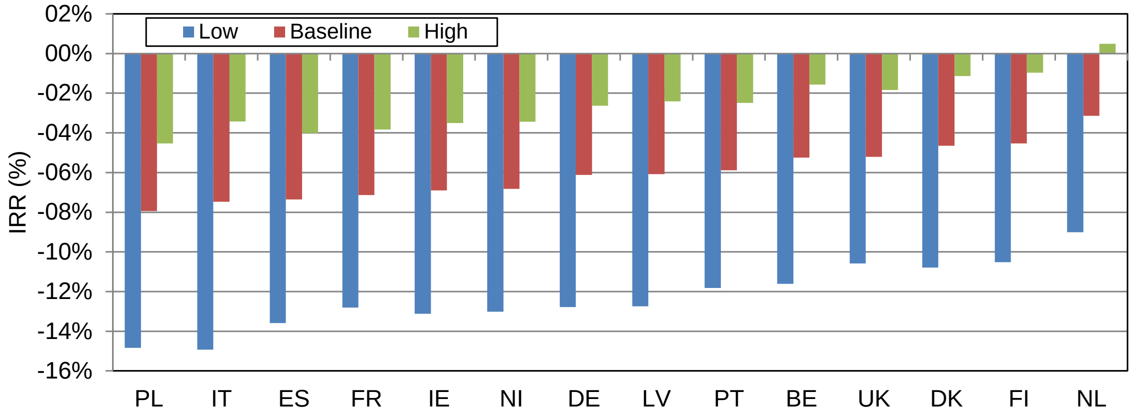


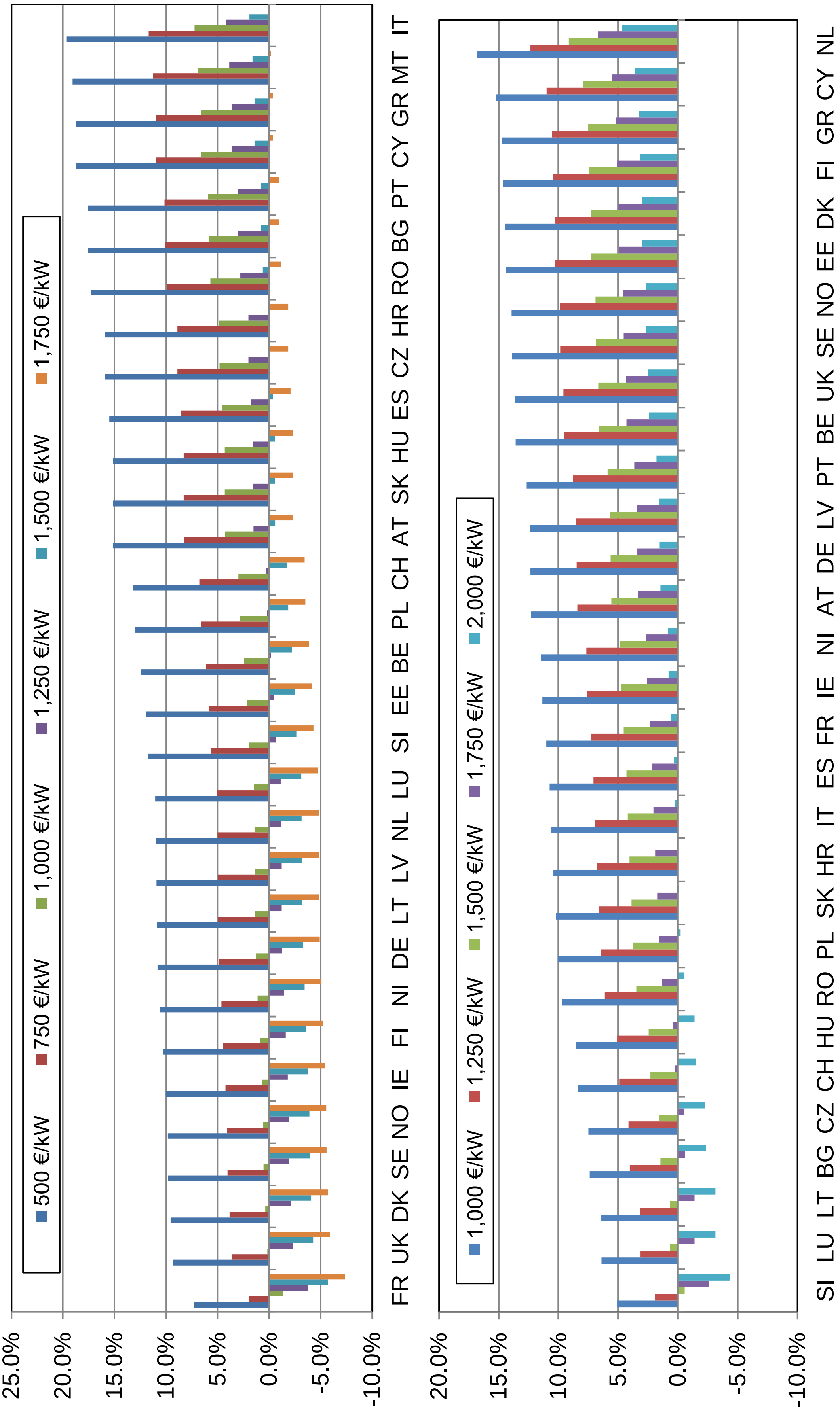
Figure 4: Impact of fuel price variations on the IRR of wind offshore investments across Europe, 2030

3.4 Impact of technology cost variations on the profitability of RES-E investments

For the considered technologies, the study by Taylor et al. (2016) suggests that there will be huge reductions of investment-related costs by 2025. However, there is obviously also a very high uncertainty related to these reductions, which is yet higher in our case given that our analysis is based on 2030. A thorough sensitivity analysis of the impact of changes in technology costs on the profitability of RES-E investments is therefore very important. We shall do this using fuel price assumptions of the baseline scenario.

Figure 5a shows how the IRR of solar PV investments changes across Europe when the specific investment costs of solar PV vary between 500 €/kW and 1,750 €/kW (where Taylor et al. (2016) expect 711 €/kW by 2025). It becomes obvious that such cost reductions lead to a step change in profitability of PV across Europe. Already a slightly less ambitious reduction to 1,000 €/kW would result in positive IRRs for the vast majority of countries in Europe and in IRRs around or above 5% for a third of the member states.

Figure 5b shows how specific investment costs of wind onshore varying between 1,000 €/kW and 2,000 €/kW affect the IRR of wind onshore across Europe (where Taylor et al. (2016) expect 1,233 €/kW by 2025). If technology costs of wind onshore remained unchanged or increased slightly, the IRRs would still be positive in most countries. However, if the specific investment costs fell to around 1,000 €/kW, the IRRs would exceed 5% across Europe, while for two thirds of the countries they would exceed 10%.



(a) *Solar PV* (b) *Wind onshore*

Figure 5: Impact of technology cost variations on the IRR of solar and wind onshore investments across Europe, 2030

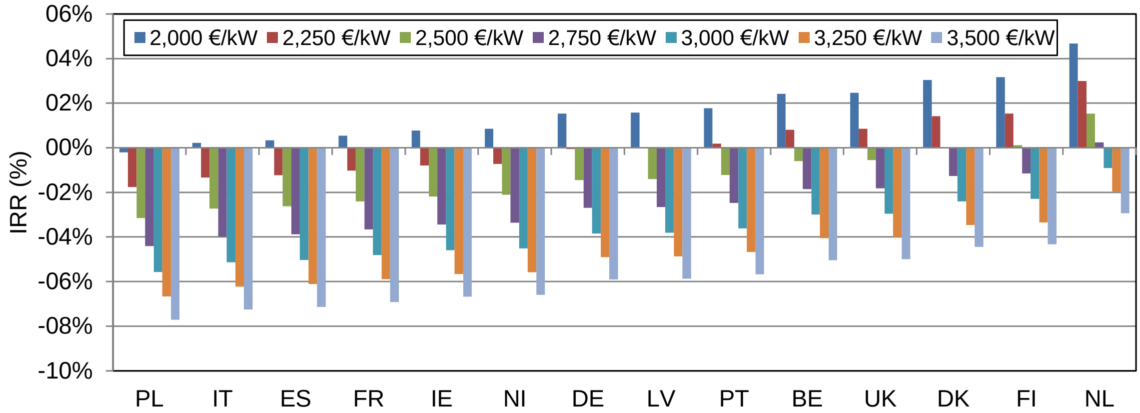


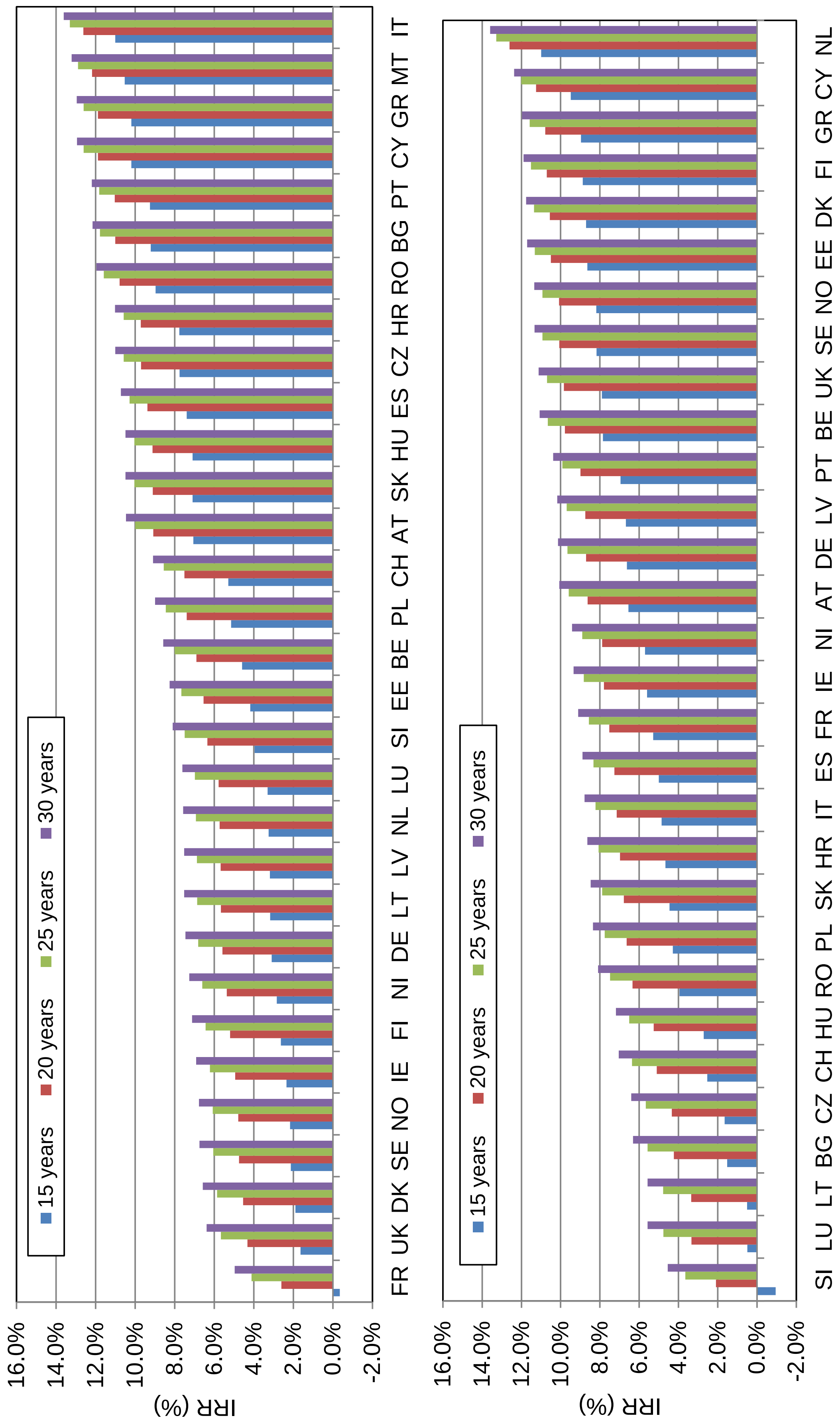
Figure 6: Impact of technology cost variations on the IRR of wind offshore investments across Europe, 2030

Figure 6 shows how technology cost variations between 2,000 €/kW and 3,500 €/kW would affect wind offshore investments. While Taylor et al. (2016) expect 3,555 €/kW by 2025, Figure 6 shows that reductions to 2,000 €/kW would be necessary to achieve a positive IRR in most countries with wind offshore potential. However, even for such significant cost reductions, the IRR would not exceed 5% in any of the countries, which may not be sufficient to make this a viable investment given the scale of offshore projects.

3.5 Impact of lifetime variations on RES-E investments

We now explore how changes in the expected lifetime of solar and wind projects affect their profitability, where our baseline assumption is 20 years (see section 2.2). Figure 7 shows that for both solar PV and wind onshore, decreasing the lifetime expectation to 15 years would result in IRRs that are around 2% lower on average. An increase in the lifetime of the projects would have a slightly lower positive effect. The IRRs for both technologies would be around 1% higher for a lifetime of 25 years (compared to 20 years), while the IRRs would increase by another 0.5% for a lifetime of 30 years (compared to 25 years).

Furthermore, Figure 7a shows for solar PV investments that a lifetime reduction to 15 years would lead to an IRR of below 4% in almost 50% of the countries. An increased lifetime of 25 years, however, would ensure an IRR of at least 6% in almost all countries. For wind onshore, Figure 7b shows that the IRR would fall below 6% if the lifetime was reduced to 15 years. A lifetime increase to 25 years, would ensure an IRR of at least 8% for two thirds of the countries. However, countries in Northern Europe (Estonia, Finland, Sweden and Norway) and Western Europe (Belgium, UK, Netherlands) as well as Cyprus and Greece achieve IRRs of around or higher than 8% for all considered lifetime scenarios.



(a) *Solar PV*

(b) *Wind onshore*

Figure 7: Impact of lifetime variations on the IRR of solar and wind onshore investments across Europe, 2030

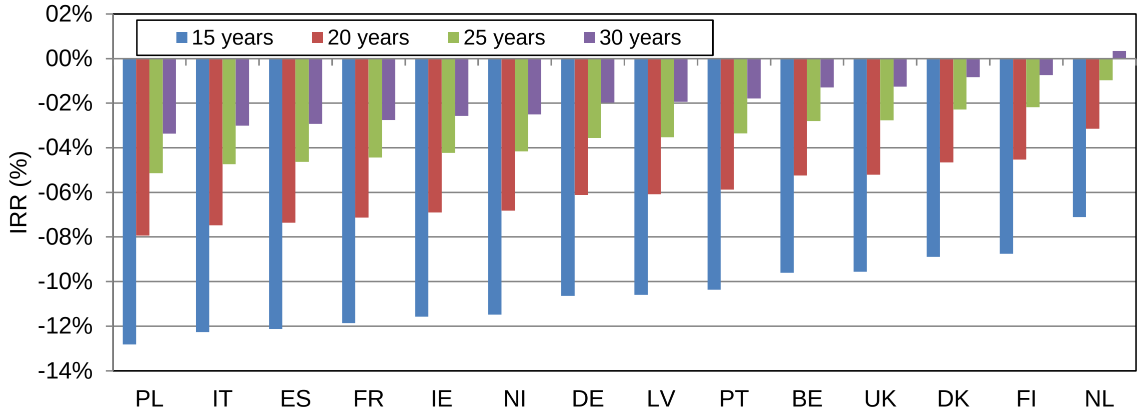


Figure 8: Impact of lifetime variations on the IRR of wind offshore investments across Europe, 2030

Figure 8 shows that the IRR of wind offshore investments is yet more sensitive to lifetime variations than the IRR of wind onshore or PV. A lifetime reduction of offshore projects to 15 years would come along with IRRs that are around 4.5% lower on average. A lifetime increase to 25 years would lead to IRRs that are around 2.5% higher on average (compared to 20 years), while the IRRs would increase by another 1.5% for a lifetime of 30 years (compared to 25 years). However, with the exception of an assumed lifetime of 30 years in the Netherlands the IRRs remain negative under all lifetime scenarios for the baseline technology cost and fuel price assumptions.

4 Discussion

The results in the previous section highlight that the market-based profitability of RES-E investments differs substantially across Europe. While some technologies are profitable in some countries without any additional subsidies, the same or other technologies are not profitable in other countries. Consequently, if all countries, for whatever reason, sought to deploy all RES technologies within their own jurisdiction, additional incentives would need to be provided to investors, which would ultimately be borne by the consumers. In theory this suggests that, as long as interconnection capacities between countries are sufficiently high, it would be more efficient to export renewable generation from countries in which natural conditions incentivise the development of renewable generation to other countries in which these conditions are less favourable. However, the issue of trading so-called Renewable Energy Certificates (RECs) or Guarantees of Origin (GOs) is debated controversially. While those in favour of an approach for cross-border trading of renewables (e.g., Perez et al., 2016) would broadly follow the same arguments outlined above, those against such an approach (e.g., Toke, 2008) would typically highlight the administrative barriers and increasing risk for investors ultimately turning into increased costs to consumers. In contrast, Green et al. (2016) propose a market design aimed at facilitating long-distance trading of renewable energy, hence mitigating existing barriers. Altogether, it should be noted that our analysis across the EU focusses on 2030 and shows that the considered RES technologies are profitable in quite a few countries without any subsidies, largely driven by cost reductions of RES technologies. This suggests that spikes of REC prices as anticipated by Haas et al. (2011) for trading-based RES support systems within individual countries should not be expected, at least not to the same extent.

In this paper, we present IRRs for different RES-E technologies across Europe. For an adequate interpretation, it is important to note that these have been calculated using wholesale electricity prices and a uniform payback period of 20 years. We acknowledge, however, that in reality there are different investors with different expectations and considerations. Energy companies or investment funds are likely investors in wind onshore capacities (García-Álvarez et al., 2017), which suggests that the use of wholesale electricity prices is adequate. In the case of solar PV, on the other hand, and indeed some wind onshore projects, likely investors also include non-energy companies (Bergek et al., 2013), whose investment considerations would be based on industrial tariffs rather than wholesale prices. In addition, the perception of regulatory or technology-related risks are important determinants of (energy as well as non-energy) firms' investment behaviour (Masini and Menichetti, 2013). Finally, residential households are very likely investors for small-scale solar PV assets. Their investment considerations are usually based on residential retail tariffs as well as a number of non-economic aspects, such as investing in green technologies or achieving a certain level of autonomy (Jager, 2006; Kwan, 2012; Graebig et al., 2014; Islam, 2014; De Groote et al., 2016; Bertsch et al., 2017a)). For the latter two (investments by non-energy companies and residential households), the IRR estimates based on wholesale prices should therefore be understood as lower boundaries as the wholesale prices are only one component of the total industrial and residential retail tariffs.

Overall, the rates of return required to undertake an investment in RES technologies vary significantly between different types of investors (Karneyeva and Wüstenhagen, 2017) and may also vary across countries. For instance, our results (see Figure 2a) show that the IRR of solar PV investments is below 7% for around half of the countries, which may not be enough to incentivise utilities to invest in this technology (Bonnafous and Jensen, 2005).

For residential households, studies show that these face a market interest rate between 1% and 3% (LaMonaca and Ryan, 2017; De Groote and Verboven, 2016) and may consider 15 years as a reasonable payback period for their investment. At the household level, the investment in solar PV may therefore be undertaken in most of the countries by 2030 (see Figure 7a).

As for wind offshore, it is interesting to observe that this technology is almost never profitable in our analysis, which concurs with findings by Green and Vasilakos (2011). However, in recent auctions held in Germany for instance, investors submitted bids for wind offshore projects without any financial support.[7] One possible reason could be that the investors expect strong reductions in investment costs associated with this technology (Radov et al., 2016). However, our analysis on the impact of technology cost variations (see Figure 6) shows that even for a reduction of wind offshore investment costs to 2,000 €/kW (i.e. a reduction to around 50% of today's costs), the IRR does not exceed 5% in any of the countries and does not exceed 3% in most countries. In order to understand under which conditions wind offshore may become profitable, we carried out an additional sensitivity analysis on the corresponding capacity factors. For this purpose, we increased the capacity factors of wind offshore in all countries proportionally reflecting technological improvements. With a capacity factor between 40 and 50% for all the countries with wind offshore potential, however, we still find that capital costs above 2,500 €/kW result in IRRs below 6% for all countries. This suggests that there may be other considerations behind these wind offshore bids. Either, the investors expect lower technology costs in combination with high fuel prices and/or longer lifetimes or they may evaluate the importance of entering in this market as a strategic option and may re-evaluate their investment decisions over time, e.g., as information about new support schemes (to be put in place by 2030) becomes available (Brown et al., 2015). However, such 'wait-and-see' strategies have been proven to be detrimental (Dedecca et al., 2016). We acknowledge that all these factors are crucial to understand the strategy of the investors in wind offshore but they cannot be included within the scope of this paper.

While the focus of this paper is the assessment of the economic viability of different renewable technologies across Europe on the basis of the IRR, there are non-economic considerations which are important, in particular for policy makers, in the context of RES-E deployment. Above, we already mentioned non-economic determinants of investments

[7] `https://www.cleanenergywire.org/news/support-free-bids-again-germanys-second-offshore-wind-auction`

such as the willingness to pay for 'green investments' or autonomy. Another crucial aspect for the successful and timely deployment of renewables is the public acceptance of these investments, i.e. not the acceptance by those investing but by those who are affected by the investments (e.g., Bertsch et al., 2017b; Hyland and Bertsch, 2018). Acceptance of renewable technologies usually depends on the technology type (e.g., solar vs. wind), the size of the investment and the geographical distance between the built capacity and the people affected (Wüstenhagen et al., 2007; Bertsch et al., 2016). For instance, studies show that (i) the social acceptance of renewable projects is inversely related to the geographical proximity to residential dwellings and (ii) that the acceptance of solar PV is much higher than that of wind onshore even at very low distances to people's homes (e.g., Bertsch et al., 2016, 2017b; Harold et al., 2018). Moreover, existing research has found that in some regions the public acceptance of wind offshore is higher than that of wind onshore (Schmidt, 2017). This is important to understand for both policy makers and investors as such considerations of public acceptance may counterbalance the economic advantages of wind onshore to some extent. While policy makers might give preference to solar PV or even wind offshore instead of wind onshore with the objective of ensuring a timely achievement of the European renewable energy targets, investors might give preference to solar PV hoping to avoid project delays. Overall, this underlines the importance of understanding the investment economics and public acceptance of different RES-E technologies as well as the tradeoffs people make and their willingness to pay for the second-cheapest or even third-cheapest RES-E technologies if their acceptance levels are higher. The analysis presented in this paper is one contribution to resolving this conundrum.

As for all quantitative studies, the analysis and results presented in this paper come along with some limitations and therefore need to be interpreted with caution. We use the internal rate of return (IRR), which is the discount rate that makes the net present value (NPV) of all the cash flows produced by a project (both negative and positive) net of the necessary investment to implement the project equal to zero. Santos et al. (2014) highlight that a real option analysis would be better suited than the IRR methodology, in particular when investors face uncertainty and may postpone their investment decision.[8] However, in the framework in this paper, we consider only one year (2030) and we acknowledge the simplifying assumption that the projects have constant annual cash flows over their lifetime. Nevertheless, the IRR gives a sound estimate of the profitability of each project,

[8]See also Ceseña et al. (2013).

and (in our specific case) is also a good measure to compare projects between different countries. Moreover, in order to calculate the costs associated with the investment in renewable generation, we assume that the costs of solar and wind technologies are the same across Europe. We acknowledge that this is a simplifying hypothesis that may be changed in future work.

5 Conclusions and policy implications

This work has estimated the marked-based profitablity of different renewable technology investments across Europe. The analysis focuses on solar PV as well as wind power (onshore as well as offshore), does not assume any separate financial support for renewables and uses the internal rate of return (IRR) as an indicator to compare the profitability between technologies and countries.

We show that investments in the considered technologies are not homogeneously profitable across Europe. Our results reveal four categories of countries. The first category includes a number of countries in Scandinavia and other parts of Northern or Western Europe where wind onshore is rather profitable, while the profitability of solar PV is low. The second category consists of a group of countries in the South-Eastern part of Central Europe (e.g., the Czech Republic, Slovakia, Hungary and Bulgaria) where solar PV is rather profitable, whereas wind onshore investments achieve very low IRRs. The third category includes countries in Central Europe (e.g., Luxembourg, Lithuania and Slovenia) where neither solar PV nor wind onshore are perticularly profitable. Finally, the fourth category consists of countries in Southern Europe with coastal access (e.g., Portugal, Greece and Cyprus) where the profitability of both solar PV and wind onshore is rather high. Wind offshore is not found to be profitable under our baseline assumptions.

We also carried out a number of sensitivity analyses to explore the impact of varying key factors, such as the fuel prices, technology costs and technology lifetimes. Our analysis shows that a reduction in the lifetime of the projects, increased technology costs / less than anticipated technology cost reductions by 2030 and lower fuel prices significantly reduce the profitability of wind and solar investments. More specifically, we observe that the downside risks and the upside potentials of the investments are distributed asymmetrically, i.e. the downside risk of lower fuel prices and shorter technology lifetimes is larger than the corresponding upside potential of higher fuel prices and longer lifetimes. In contrast, the upside potential of decreased technology costs is larger than the downside risk of increased costs. All these factors need to be taken into account when assessing whether the investments in renewables will meet the 2030 targets in the absence of any financial supports by Member States or what form and level of support may be required in different states to meet the targets.

There are a number of messages that policy-makers can take away from this research. *First*, our analysis shows that allowing for some form of trading renewable generation between countries or providing some other mechanism for joint target achievement / co-operation between European countries (as opposed to national targets that have to be met nationally only) can be expected to achieve the overall targets at lower costs. Comparing the 2030 target shares (Figure 1) and profitabilities (Figure 2) reveals that some countries have high RES-E targets while the profitability is rather moderate or low and vice versa. This suggests that either financial support payments will be required (ultimately leading to higher costs to consumers) to meet the targets in these countries or the targets may not be met. Trading of renewable generation between countries can resolve both problems. Should countries, for whatever reason, wish to achieve certain technology-specific national targets, our analysis provides quantitative support in determining which technologies need support in which countries. Moreover, our analysis shows that in most countries at least one technology (wind onshore or solar PV) is profitable by 2030 even in absence of any financial support payments. *Second*, our analyses provide insights for policy makers as to how sensitive a successful RES deployment and target achievement are to uncertainties related to different factors. For technology developers, these analyses can be used to derive targets in relation to technology cost reductions and lifetimes. *Third*, our results show that in quite a few countries, wind onshore is more profitable than solar PV, and definitively more profitable than wind offshore. Beyond these economic considerations, however, the public acceptance of energy infrastructure investments is a prerequisite for a successful deployment of renewables, which has been shown to be higher for solar PV and wind offshore compared to wind onshore in many cases as discussed in section 4. It is therefore crucial for policy makers to have an open and transparent discourse about the tradeoff people make between consumer costs (depending, amongst others, on the profitability of investments) and acceptance related to different renewable technologies. The analyses presented in this paper provide an important contribution to understanding the investment economic side of this tradeoff.

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