**Grant agreement no. 730403**

# INNOPATHS

## Innovation pathways, strategies and policies for the Low-Carbon Transition in Europe

***H2020-SC5-2016-2017/H2020-SC5-2016-OneStageB***

# D2.5 Report on the successful management of innovation for the energy transition

Work Package: WP2

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Contributors: *CMCC, UCAM, SPO*
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|---|---|---|
| **Dissemination Level** *(please refer to the list of deliverables and complete also footer)* | | |
| **PU** | Public | X |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |
| **CI** | Classified, as referred to in Commission Decision 2001/844/EC | |



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# 1. Version log

| Version | Date | Released by | Nature of Change |
|---|---|---|---|
| 1.0 | 10/10/2019 | LDA (UCAM) | Draft of third contribution |
| 1.1 | 07/11/2019 | JE (CMCC) | Draft of second contribution |
| 1.2 | 20/11/2019 | MG (CMCC) | Draft of first contribution |
| 1.3 | 13/11/2019 | EV (CMCC) | Revised and harmonized all contributions |
| 2.0 | 15/11/2019 | YJK (CMCC) | Reviewed draft |
| 3.0 | 13/05/2020 | EV (CMCC) | Included additional contribution in deliverable |



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## 2. Definition and acronyms

| **Acronyms** | Definitions |
|---|---|
| LIB | Lithium-Ion Batteries |
| IAM | Integrated Assessment Model |
| WITCH model | World Induced Technical Change Hybrid model |
| O*NET | Occupational Information Network (US) |
| EU-LFS | European Labour Force Survey |
| EPS | Environmental Policy Stringency |
| SSP | Shared Socio-Economic Pathway |
| | |



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# 3. Introduction

This Deliverable describes the research work carried out in Task 2.2. of the INNOPATHS project. Task 2.2. focused on labour dynamics and spillovers. These are two key aspects of the innovation process which are relevant for the energy transition, and which will need to be appropriately accounted for and managed for the success of this process. The task is composed of four contributions.

**First contribution:**

CMCC and SPO provided novel evidence on the interplay between energy and climate policies, the innovation process and labour force composition. Specifically, CMCC and SPO (1) developed a new methodology to measure the greenness of EU jobs, and their green skills content, at the sectoral level, starting from available literature on this topic focused on the USA (Vona et al. 2018 and Vona et al. 2019). CMCC and SPO also (2) provide descriptive statistics of this indicator across countries and sector. This report provides three contributions: First, the development of a taxonomy of green jobs for Europe, by matching information on green task content of jobs provided in the US Occupational Information Network (O*NET) with the occupational data in the EU Labour Force Survey (EU-LFS) to overcome the lack of data on greenness of jobs in Europe. Second, the description of the evolution of the greenness indicator and of the key green skills in different sectors of the EU member countries. Third, an initial descriptive evidence of whether and how the evolution of the greenness indicator and of green skills correlate with more stringent environmental policies, reduced emissions or higher level of green innovation for the EU.

A more detailed report for this contribution is provided in Annex A

**Second contribution:**

CMCC integrated endogenous labour supply and leisure preferences in the Integrated Assessment Model (IAM) WITCH, along with unemployment and the evolvement of active population rather than total population. This is a significant improvement to the literate: in most IAMs, the factor labour is considered as simply based on the population size of countries and regions all being active in the productive sectors. For this part of the task, CMCC projects employment and long term preferences over time allocation for different regions of the world and discusses their long-term macro implications. CMCC develops the standard utility function of a Ramsey-type optimal growth model to account for a ‘market-time’ vs. ‘free-time’ trade-off. To do so, a free-time preference coefficient is introduced in the formulation, which measures the utility gained by deviating from a maximum labour supply. This voluntary employment or free-time preference coefficient is then calibrated based on statistical and projected data from the United Nations, the International Labour Organisation and the OECD. Lastly, CMCC shows how energy and carbon intensities in the baseline or mitigation scenarios vary with employment and leisure or working hours.

A more detailed report of this contribution is presented in Annex B

**Third contribution:**

UCAM performed a systematic evaluation of to understand the role of technology spillovers from other sectors in specific areas of the energy sector and, most importantly, to understand how those spillovers took place. The motivation of this component was that, while technology spillovers have been widely recognized as motivators for policy and enablers of innovation in general, most of the work trying to understand spillovers relies on patent citations. While previous analysis of spillovers



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using patent citations in broad technological areas and, more recently, in specific technologies (i.e. solar PV and lithium-ion batteries) allow researchers to understand at a high level what industries broadly have contributed to patents that are cited in patents that have been classified under particular technology categories, this approach does not allow researchers to understand how the spillover took place. In other words, there was a gap regarding the policy (or otherwise) mechanisms that can enable spillovers.

To understand at a more granular level where spillovers come from (beyond industries) and what enables them, T2.2 researchers, working with two colleagues at ETH Zurich (Prof. Volker Hoffmann and Dr. Annegret Stephan), investigated the key breakthroughs that enabled the commercialization of lithium ion batteries, identified which ones can be classified as knowledge spillovers, and determined how they came about. Lithium-ion batteries were selected both because they can play a major role in decarbonizing both the transport and power sectors, but also because of the major cost-reductions that we have seen over the past 30 years.

A draft article (Stephan, Anadon and Hoffmann 2019, attached as Appendix 3 in this report) describing the research carried out and the results will be drafted and submitted to a peer-reviewed journal in the coming months.

**Fourth contribution:**

Innovation in clean energy technologies is central to achieving a net-zero energy system. Given the urgency of climate change mitigation, policymakers and managers of public research organizations are interested in how to best support innovation in clean energy technologies. One key determinant of technological innovation in clean energy technologies that have been underexplored is the transfer or integration of external knowledge, i.e., of knowledge spillovers.

A major concern in this respect is the fragmentation of the EU innovation system). Similarly to the arguments supporting the creation of a single market, an integrated EU innovation system was promoted as a way for EU countries to benefit from their neighbours, on the assumption that more integrated research efforts would give rise to a virtuous circle, reducing the duplication of research efforts and allowing each country to learn and benefit from the knowledge of other members. Conversely, a disparate and fragmented research and development effort would translate into an “insufficient capacity to innovate, to launch new products and services, to market them rapidly on world markets and, finally, to react rapidly to changes in demand”. In the specific case of renewable energy technologies, several analyses demonstrate that the introduction of demand-pull measures provided incentives to RES innovation and deployment. However, fragmentation remains one of the most crucial concerns, potentially delaying, or even impeding, the achievement of the ambitious EU climate targets. For instance, in 2006 the EC called for the establishment of a EU Strategic Energy Technology Plan, recognizing past efforts in RES research and development, but claiming a still “scattered, fragmented and sub-critical” RES innovation space, which needed greater integration and coordination of Community and national research and innovation programs and budgets, under the aegis of agreed EU-level goals (EC, 2006). Thus, a less fragmented EU RES innovation system is believed to be instrumental to exploiting the federating role that the European Union can play in the field of energy and to meet the challenge of developing a world-class portfolio of affordable, competitive, efficient and low-carbon technologies while creating stable and predictable conditions for industry (EC, 2006). Along similar lines, in a later communication the European Commission argues that “the fragmentation, multiple non-aligned research strategies and sub-critical capacities that remain a prevailing characteristic of the EU research base” are critical factors constraining EU firms’ innovative capability (EC, 2007). This analysis contributes to the literature by investigating the fragmentation of the EU



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innovation system in the field of renewable energy sources. This crucial aspect of renewable energy innovation dynamics has not received attention to date. Understanding how knowledge flows among EU countries and between the EU and other top innovators have evolved over time is important because it can shed light on the effectiveness of past actions and policy support to promote RES development and the integration of the RES innovation space in the EU, as well as drive future policies in this respect.

An article (Conti et al. 2018) was published in Research Policy (attached as Appendix 4 in this report)

# 4. Activities carried out and results

**First contribution:**

To provide a descriptive evidence on the evolution of green jobs, CMCC and SPO built on the methodology first developed in Vona et al., (2018) and Vona et al., (2019) to compute a greenness indicator and to define the skills content of an occupation. Throughout the report, "task" and "skills" are defined according to the seminal work of Autor, Levy and Murmane (2003) and of Acemoglu and Autor (2010). An "occupation" or "job" consists of a set of different tasks, which are the units of work activity that produces some output. To perform a set of tasks, the worker will rely on a set of "skills" (i.e., competencies), which are the endowments of capability that allow him to get the task done. As a simple example, "monitor and evaluate the effectiveness of sustainability programs" is one of the tasks in the "Chief Executive" occupation; a skill necessary to perform this task is "economics and accounting".
The methodology developed by CMCC and SPO was designed to overcome the fundamental lack of data on the green content of EU jobs. This methodology can be described by the four step below:

a) The computation of greenness and skills by occupation in the US. This steps effectively reproduce the methodology adopted in Vona et al., (2018) and Vona et al., (2019) to compute a greenness indicator and to define the skills content of an occupation, with a more recent version of the O*NET database;
b) The computation of greenness and green skills by occupation in the EU. This step requires matching jobs in the US, which are classified using the SOC[1] classification, to jobs in the EU, which are classified using the ISCO[2] classification;
c) The computation of greenness and green skills by sector in the EU member countries. This step entails attributing EU jobs to specific sectors within the EU;
d) The descriptive analysis of how EU green jobs correlate with more stringent environmental policies (proxied by energy price and EPS), with emissions reductions (i.e., CO2 emissions embedded in trade) and with innovation (i.e., patents application and their stock) either at the sector or at the national level.

For what regards the sector-level greenness indicator, the results of this analysis show that greenness in European jobs is rather low on average across sectors and countries, as illustrated in Table 1. In detail, Construction has the highest average greenness in

[1] Standard Occupation Classification is the employment taxonomy applied in the US
[2] International Standard Classification of Occupation is the employment taxonomy by the International Labour Organization and applied in the EU



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the EU (0.0909), while Utilities follows with an average greenness of 0.074. Manufacturing is the third greenest sector, scoring 0.0583. Figure 1 shows the sectoral greenness indicator trend in 2008-2014 for countries with emissions higher than (resp. lower) the EU emission average, in these three sectors. The figure shows a homogeneous trend of the greenness indicator for the Construction sector: the growth is stunning and on average, in 2014, greenness was 2% higher than in 2008. Conversely, the growth of greenness in the Utility sector is more heterogeneous across countries. Some high emissions countries substantially increased their greenness during the period, whereas others show a flatter trend. Better performances are shown by low emitters which mostly experienced an increase in greenness. The Manufacturing sector had an overall minor decrease during the period. Evidence at the country level is mixed: some countries experienced an increase in the indicator, some a decrease. This is true for both high emissions and the low emission countries. Nevertheless, with a few exceptions, the greenness of the Manufacturing sector is still higher than the average at the EU level.

*Table 1 – Greenness by NACE*

| *Country* | **Agriculture, Fishing & Hunting** | **Manufacture** | **Utilities** | **Construction** | **Transport & Warehousing** | *Avg. by country* | *(std.dev)* |
|---|---|---|---|---|---|---|---|
| Austria | 0.0001 | 0.0645 | 0.0555 | 0.0700 | 0.0223 | 0.0555 | 0.0151 |
| Belgium | 0.0004 | 0.0493 | 0.0575 | 0.0883 | 0.0270 | 0.0517 | 0.0107 |
| Germany | 0.0157 | 0.0479 | 0.0515 | 0.0599 | 0.0236 | 0.0456 | 0.0130 |
| Denmark | 0.0000 | 0.0601 | 0.0851 | 0.0930 | 0.0188 | 0.0546 | 0.0122 |
| Spain | 0.0109 | 0.0586 | 0.0947 | 0.0877 | 0.0217 | 0.0573 | 0.0105 |
| Finland | 0.0154 | 0.0616 | 0.0910 | 0.0900 | 0.0192 | 0.0585 | 0.0121 |
| France | 0.0123 | 0.0558 | 0.0875 | 0.0764 | 0.0317 | 0.0545 | 0.0103 |
| Greece | 0.0001 | 0.0401 | 0.0690 | 0.0986 | 0.0117 | 0.0328 | 0.0059 |
| Ireland | 0.0027 | 0.0580 | 0.0581 | 0.0761 | 0.0288 | 0.0530 | 0.0180 |
| Italy | 0.0030 | 0.0393 | 0.0520 | 0.0905 | 0.0251 | 0.0426 | 0.0089 |
| Netherlands | 0.0177 | 0.0592 | 0.0690 | 0.0846 | 0.0251 | 0.0547 | 0.0114 |
| Poland | 0.0091 | 0.0574 | 0.0691 | 0.0997 | 0.0342 | 0.0608 | 0.0117 |
| Portugal | 0.0038 | 0.0359 | 0.0851 | 0.0947 | 0.0194 | 0.0431 | 0.0076 |
| Sweden | 0.0151 | 0.0627 | 0.0859 | 0.0879 | 0.0292 | 0.0604 | 0.0111 |
| United Kingdom | 0.0132 | 0.0735 | 0.0636 | 0.0951 | 0.0291 | 0.0678 | 0.0147 |
| *EU mean* | 0.0090 | 0.0583 | 0.0740 | 0.0909 | 0.0269 | | |
| *(std.dev)* | 0.0005 | 0.0038 | 0.0041 | 0.0048 | 0.0013 | | |

Note: EU mean by sector is computed as a weighted average where weights used are the relative size of a sector in a country over the total value added created in the same sector in the EU economy. Avg. country is computed as a weighted average within the same country where weight used the relative size of a sector over the total value added generated by the five sectors in each country.



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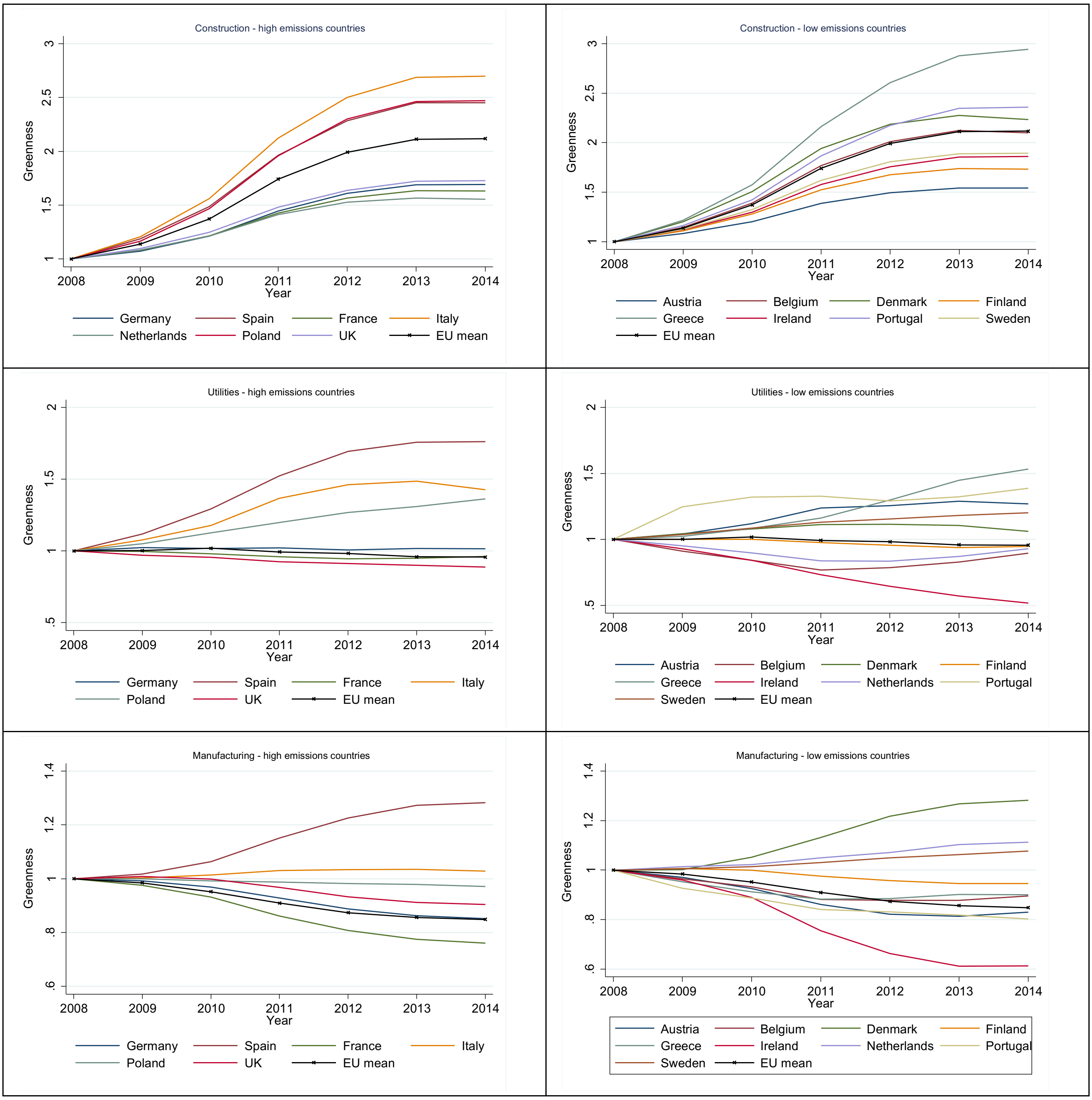
*Figure 1 – Greenness trend by selected by NACE Rev.2 Sections. 2008-2014, 2008=100. Data Source: Onet 23.1 and EU Labour Force Survey (2014)*




Results also show a positive association between greenness and energy prices: on average, a 1% increase in energy prices is associated with 0.04% increase in greenness. However, when we condition on value added, the coefficient associated with energy prices is no longer significant. Greenness is also positively correlated to the EPS indicator. Yet, if we condition of each country's gross domestic product, the estimated association is negative. Finally, there is a positive correlation also between greenness and the technology variables, i.e. patent applications and their stock.



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**Second contribution:**

We developed an analytical labour market model and added it in the WITCH IAM. Secondly, data was collected on different population cohorts, unemployment rates, educational attainment, and tax rates to be able to calibrate the model at the country level. Finally, all data has been aggregated to the WICTH17 regions to be able to be used in the integrated assessment model. Based on the labour-enhanced WITCH model, scenarios were performed under different assumptions about the labour market and leisure preferences.

Overall, working hours have declined from about 3000 hours per year at the beginning of the industrialization to about 2000 hours by 1960, and further to between 1500 and 1800 hours per year as of 2015. We project this trend to continue in the short term implying higher values of leisure. This effect is highest in countries for which we compute high values of leisure preference, notably Europe, but also Latin American countries among developing economies. Endogenous leisure decisions however produce also the effect in some regions of increased working time resulting overall in GDP gains of about 6% by the end of the century compared to a standard SSP2 scenario. This translates into a total primary energy increase by 4% and 3% higher baseline emissions. In the 1.5 degrees scenario, on the other hand, the impact is changing over time leading to a slight reduction in emissions in the long term by 2100.

The results of the model shed light on the interplay between climate policies, demand for labour and innovation (a key feature of the WITCH model), and on the effects of low-carbon technologies on inequality through changes in the wage and leisure dynamics. While the distinction of different skill levels is challenging in such models, the impact on the energy mix and emissions of labour in general can still be assessed through the general equilibrium framework. Further availability of global coverage of skill sectoral and greenness indicators will enable to implement different types of skills also in an IAM.

**Third contribution:**

Innovation in clean energy technologies is central to achieving a net-zero energy system. Given the urgency of climate change mitigation, policymakers and managers of public research organizations are interested in how to best support innovation in clean energy technologies. One key determinant of technological innovation in clean energy technologies that have been underexplored is the transfer or integration of external knowledge, i.e., of knowledge spillovers. Spillovers can substantially advance technological innovation (Mowery and Rosenberg, 1998; Scherer, 1984, 1982a, 1982b; Schmookler, 1966), which has empirically been also shown in the fields of clean energy (Huenteler et al., 2016a; Nemet, 2012), storage (Noailly and Shestalova, 2016) and battery (Battke et al., 2016) innovations

While the literature has described general patterns of knowledge spillovers in clean energy technology innovations--typically by analyzing large sets of patent data—these quantitative studies lack explanatory power how individual spillovers come about: of the mechanisms and enablers of these spillovers.

In this research, UCAM addresses this gap asking how knowledge from other technologies, sectors or scientific disciplines is integrated into the innovation process in an important technology for a net zero future: lithium-ion batteries (LIB). We conduct a qualitative case study to allow us to understand *how* (Yin, 2009) the integration of external knowledge happened. Empirically, we perform a qualitative case study of spillovers in LIB innovations based on a literature review on the evolution of LIBs and



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on spillovers and an elite interview campaign with R&D/industry experts and key inventors in the LIB field.

The analysis draws on two data sources: literature research and semi-structured elite interviews with key actors in the LIB field, i.e., R&D and industry authorities/experts and well-known senior-level inventors of LIB innovations. The methodology applied followed Tansey (2007): researchers sampled the interviewees (elites) in a purposive, non-probability (i.e., non-random selection) way. In contrast to random sampling, this strategy allows for a real-time and first-hand participant observation of the key actors in the field. Researchers identified an initial subset of interviewees based on literature research, and then initiated a snowballing system whereby the initial interviewees were asked to recommend further experts in that area (Tansey, 2007). Researchers talked to eight interviewees, of which half were inventors and half were R&D and industry authorities/experts.

The UCAM research makes three main contributions to the literature on spillovers. First, seven key breakthrough LIB innovations are identified. Second, the research shows the extent to which breakthroughs and a few others have resulted from the integration of knowledge from a variety of sources (i.e., different areas of technologies, sectors and scientific fields); often a spillover only happened because of a combination of different sources. Third, different mechanisms and enablers underlying spillovers in LIB innovation were identified, including public research funding providing important researcher autonomy and the interdisciplinary structure of education and research teams. Fourth and last, this work allowed to identify a set of levers for decision makers in policy, academia, and industry who want to facilitate spillovers in LIBs and other clean energy technologies.

This analysis and data support four different mechanisms of how spillovers can happen. First, spillovers can occur because people (e.g., inventors) change the technological field, sector or have moved between different scientific disciplines. Second and related, spillovers can occur because people (inventors) receive interdisciplinary education or nurture interdisciplinary interests. Third, spillovers occur because of communication or contact between individuals. Fourth, the access to and the reading of publications such as academic papers, industry reports and press releases can also help to acquire external knowledge, as it happened in the field of LIB innovations. These mechanisms were facilitated by five enablers: the structure of public funding in some cases, which provided freedom of search, the existence of interdisciplinary education and exchange programs, the management and organization in space of R&D groups (including hiring), firms working across multiple sectors, and public interest in an issue.

We emphasize two caveats that might limit the external and internal validity of these findings. First, we analyze the specific case of LIBs. For example, LIBs exhibit specific technology characteristics such as high complexity, or mass-production, which might also affect innovation patterns (Huenteler et al., 2016b; Stephan et al., 2017). Second, our findings are constrained by the data sources available. While the elite interviews allow for a first-hand participant-observation of the innovations, our results are limited to the understanding and framing of the individual interviewees.

**Fourth contribution:**

This analysis explores on the intensity and direction of intangible knowledge flows over the years 1985–2010 using information on patent applications and citations at the European Patent Office (EPO). The focus is on the three main innovating regions of the world: the US, Japan and the EU15, which together account for roughly 87% of innovation in this field in our sample. In line with a rich literature on similar subjects, we follow the paper trail left by within-country and cross-country patent citations, using



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citation frequencies to explore the patterns of knowledge flows within the EU and between the EU and other top innovators. We modify the original double exponential knowledge diffusion model of Caballero and Jaffe (1993) to provide information on the degree of integration of EU countries' innovative efforts and to assess how citation patterns changed over time.

The analysis show that indeed EU RES inventors have increasingly built “on the shoulders of the other EU giants”, intensifying their citations to other member countries and decreasing those to domestic inventors. We show that these effects are not driven by Germany, the EU top innovator, nor are they simply the result of increased collaboration in patenting or of an increase in patent quality. Furthermore, we find that the EU strengthened its position as source of RES knowledge for the US. The analysis also compare RES to other relevant technologies in order to gain evidence on whether the observed patterns are common to other technology fields, starting by considering fossil-based energy technologies and then comparing RES to a set of emerging technologies (3D, IT, Biotechnologies and Robot technologies) to assess if our results are specific to RES or common to booming technologies at an early stage of development. Results show that the pattern of knowledge flows and its evolution in time is peculiar to RES, with traditional (i.e. fossil-based) energy technologies and other new technologies behaving in a completely different way. These results support the claim that the EU reduced the fragmentation of the innovation space specifically in the field of RES over the sample period. This analysis thus presents suggestive, but convincing evidence that the reduction in fragmentation was brought about by the strong support of the EU to climate mitigation and renewable energy technology development vis-à-vis the laxer effort put forward by the US and Japan in this respect.

# 5 Conclusions

**First contribution:**

CMCC and SPO developed a new methodology to measure the greenness of EU jobs, and their green skills content and provided a description of these indicators across 16 countries and five sectors of the green economy. The novelty of this report is the development of a taxonomy for green jobs in the EU, which was previously lacking. CMCC and SPO did this by expanding the methodology in Vona et al., (2018) and Vona et al., (2019), which relied on US data.

The report shows that the greenness of EU jobs is rather low. This notwithstanding, Construction, Utilities and Manufacturing are the three sectors which have been better able to integrate and exploit green jobs over time and that the importance of the green skills follows the same distribution. Moreover, it also shows that there is a positive correlation between policy stringency (captured by energy prices) and a rise in greenness at the sector level. Similarly, greenness and innovation also appear to be positively correlated.

**Second contribution:**

In the last 70 years, in developed countries, preferences for time allocation between market and free time have been evolving with the increase in prosperity. But evolutions have been different and cannot be explained by the growth in GDP alone. A large part of the world, the so-called fast growing countries, are not entering a phase where preferences for time allocation will potentially change in a dramatic way. This will have a large impact on what is the expected growth of these countries. Although important as a task per se, producing the long term growth projections for these fast growing



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countries is all the most crucial as the demand for natural resources will largely come from these countries. We show that projections of time use preferences could affect dramatically the world we will be living in. Henceforth, long term analysis of sustainable development cannot abstract from this key issue. The different preference parameters and scenarios, through their compared impacts on GDP, time allocation, energy consumption and carbon emissions, also give a notion of the vastly contrasted development perspectives that the introduction of a labour supply vs. free time trade-off opens.

More generally, our model enhancement is the first large-scale IAM to explicitly consider labour different from simply calibrated to a region's population, by taking into account unemployment, the active population, and endogenous labour leisure decisions. The results indeed indicate strong impacts on GDP and energy demand and hence emissions. Given the demographic SSP based calibration of the active population, endogenous leisure decision and (for now static) unemployment, this provides the first important step in integrating labour productivity and employment in in IAM. This model thus has the potential to substitute a micro-funded, comprehensive approach. Future research building on this model would be linking unemployment with energy system transformation (with at stake about 11 million direct jobs in the energy system only in Renewables in 2018 (IRENA 2019)), labour productivity changes, and the skill dimension. Moreover, a changing retirement age resulting in different active population scenarios can be analysed.

The resulting climate is also remarkably affected by leisure related emissions resulting in a temperature about 0.3 degrees higher in the BAU scenario than with fixed population as labour. This results shows that considering the changes in regional labour and leisure preferences and behaviour will possibly have a stark impact on the degree of climate change.

In terms of overall Energy and Carbon intensity, we find that from today's values of about 10 MJ/$ and 70 gCO2/MJ, the improvements in terms of energy efficiency are faster (pink vs. blue squares) in the base line at only moderate carbon intensity improvements. In the 1.5 degrees scenario on the other hand, labour preference needs to a lower energy intensity (green vs. brown) while the ranking in terms of ultimate carbon intensity is ambiguous and switches sign between 2050 and 2100

**Third contribution:**

This contribution analysed how external knowledge is integrated in the innovation process. Empirically, researchers performed a qualitative case study of lithium-ion batteries (LIBs) based on literature and elite interviews. First, they identified the key breakthrough LIB innovations. They also found striking agreement across experts regarding what are the key breakthrough innovations. Second, they showed the extent to which breakthroughs and a few others have resulted from the integration of knowledge from a variety of sources (i.e., different areas of technologies, sectors and scientific fields); often a spillover only happened because of a combination of different sources. Third, they identified different mechanisms and enablers underlying spillovers in LIB innovation, including public research funding providing important researcher autonomy and the interdisciplinary structure of education and research teams. Fourth and last, they pointed to a set of levers for decision makers in policy, academia, and industry who want to facilitate spillovers in LIBs and other clean energy technologies.

**Fourth contribution:**

This analysis investigated the fragmentation of the EU innovation system in the field of renewable energy sources (RES) by estimating the intensity and direction of



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knowledge spillovers over the years 1985–2010. The research relies on an empirical approach rooted in the original double exponential knowledge diffusion model proposed by Caballero and Jaffe (1993) to provide information on the degree of integration of EU countries' RES knowledge bases and to assess how citation patterns changed over time. Results show that EU RES inventors have increasingly built "on the shoulders of the other EU giants", intensifying their citations to other member countries and decreasing those to domestic inventors. Furthermore, the EU strengthened its position as source of RES knowledge for the US. Finally, we show that this pattern is peculiar to RES, with other traditional (i.e. fossil-based) energy technologies and other radically new technologies behaving differently. These results provide suggestive, but convincing evidence that the reduction in fragmentation emerged as a result of the EU support for RES taking mainly the form of demand-pull policies.

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