



MACROECONOMIC MODELLING OF R&D FOR THE TWIN TRANSITION

D3.2 | NEMESIS Update &

Author(s) Pierre Le Mouël (SEURECO), Jean-Patrick Le Mouël (SEURECO), Baptiste Boitier (SEURECO), Paul Zagamé (SEURECO), Hajar Sriri (SEURECO), Clara Cagnato (SEURECO) and Benjamin Puiseux (SEURECO)

Version

Date 15 April 2026

Dissemination level PU

Grant Agreement N° 101132170

Starting Date 01-01-2024

Duration 36 months

Coordinator Leonidas Paroussos (E3-Modelling)

E-mail paroussos@e3modelling.com



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Document History

Date	Contributors	Action	Status
15 April 2026	Pierre Le Mouël (SEURECO), Jean-Patrick Le Mouël (SEURECO), Baptiste Boitier (SEURECO), Paul Zagamé (SEURECO), Hajar Sriri (SEURECO), Clara Cagnato (SEURECO) and Benjamin Puiseux (SEURECO)	Update & Upgrade of NEMESIS on Digital Technologies	Draft (V1.0)
15 April 2026	Sakis Morfis (E3M)	Content and structure review	Draft (V1.1)
15 April 2026	Pierre Le Mouël (SEURECO), Jean-Patrick Le Mouël (SEURECO), Baptiste Boitier (SEURECO), Paul Zagamé (SEURECO), Hajar Sriri (SEURECO), Clara Cagnato (SEURECO) and Benjamin Puiseux (SEURECO)	Consolidation of the document review and finalisation	Final (V2.0)



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Executive Summary

This technical report presents the general methodology followed for modelling green and digital technologies in NEMESIS within the context of the TWINRD project's Work Package 3.2. It provides all the necessary information for using the Python code that was developed and made available in the [TWINRD project community's Zenodo ¹repository](https://zenodo.org/communities/twinrd-project/).

The innovation module developed can be implemented in any existing macroeconomic model. In addition to the Python code enabling the creation of all modelling objects—namely (1) scalars (parameters), (2) variables (time series), and (3) equations—all the necessary raw data are also available on Zenodo under the TWINRD project deliverables D2.1 and D2.2.

The latter datasets include:

- (1) R&D time series by country, NACE sector, technology, and combinations of technologies; and
- (2) technology flow matrices capturing knowledge exchanges between countries, sectors, technologies, and combinations of technologies simultaneously.

The tasks foreseen in the Description of Work for Work Package 3.2 ("Update and Upgrade of NEMESIS") were:

- **Sub-task 3.2.1** – A detailed ICT module will be introduced in NEMESIS to allow precise mapping of ICT and digital technologies to the economic sectors represented in the model. To achieve this, the number of NEMESIS sectors will be extended using PREDICT data, which disaggregates the ICT sector into up to 22 economic activities. Regarding R&D, data from PREDICT and Task 2.2 will enable accurate mapping of the 4IR technologies introduced in the model to economic sectors. Technology flow matrices produced in Task 2.1 will allow representation of R&D knowledge exchanges between sectors producing 4IR technologies, as well as between these sectors and other economic sectors, at the international level. Trade relations between sectors and countries will further enable modelling of productivity spillovers from technology-producing sectors/countries to user sectors, notably in service industries.
- **Sub-task 3.2.2** – All data required to represent innovation in the model will be updated, including R&D data for all sectors covered by NEMESIS, sourced from PREDICT, EUROSTAT, and ANBERD, as well as ICT and other intangible investments from the EU-KLEMS, INTANProd, and INTAN-Invest databases.
- **Sub-task 3.2.3** – The innovation module of NEMESIS, updated with new data and enhanced to better represent ICT/digital technologies, will be recalibrated and tested.

Sub-task 3.2.1 consisted of increasing the number of NACE sectors detailed in NEMESIS to better represent sectors that invent, develop, and produce new technologies. Sub-task 3.2.2 focused on updating and adapting all necessary data for modelling, while Sub-task 3.2.3

¹ <https://zenodo.org/communities/twinrd-project/>



focused on developing the innovation module for ICT/digital technologies and implementing it in the NEMESIS model.

Beyond these three tasks focused on digital technologies, we decided to also include the modelling of green technologies. As a result, the innovation module enables representation of all key technologies involved in the twin transition (green and digital), including their interactions. It can therefore be directly implemented in the new TWINRD model developed under WP4. Consequently, this deliverable also represents a major contribution to WP4 (“TWINRD model”).

We also note that designing, developing, and coding this innovation module required overcoming several unforeseen challenges, mainly due to:

- The very large number of scalars, variables, and equations required to represent innovation at the detailed technological level considered in this project (up to 66 green technologies and 23 digital technologies, plus an “Other” category, and their possible combinations). **This could potentially lead to the creation of thousands or even millions of objects, exceeding the memory and computing capacity of standard laptops and of the Pyiode package used to run NEMESIS and TWINRD.**
- **The discrete nature of patent, R&D, and citation data at this level of detail.** Not all countries and sectors invest in all technologies or produce patents for them, making it impossible to rely on traditional cartesian indexing approaches used in macroeconomic modelling. Only a limited subset of possible combinations actually exists, which reduces the number of objects but requires highly specific (non-generic) coding approaches.

These challenges were successfully addressed, but they had significant implications for the time and resources required. SEURECO developed dedicated modelling tools involving thousands of lines of code to handle discrete key structures for parameters, variables, and equations.

The remainder of the document is organised as follows:

After a general introduction, Section 1 presents the state of the art of innovation modelling in existing macroeconomic models and the rationale for the innovation module dedicated to the twin transition that is being developed in the context of the TWINRD project.

Section 2 describes the work carried out to update the patent, R&D and citation datasets that were published in July 2025 under Deliverables D2.1 and D2.2.

Section 3 presents the general empirical framework followed to develop the TWINRD innovation module and details the data and equations on which it is based. Although the current focus remains on technology production, the general framework for representing technology adoption, which is being developed in WP4, is also presented.

Section 4 informs potential users of the TWINRD innovation module about the volumetry it implies in terms of the number of objects to be created and loaded into their simulation



systems, depending on the number of detailed technology clusters they wish to include in their macroeconomic model.

Section 5 provides general guidelines to users of the TWINRD innovation module on the practical ways of linking this module to their own macroeconomic model.

Section 6 provides the conclusions and outlines the next steps of the project, including future developments of the innovation module and its extension towards the modelling of technology adoption.



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List of Acronyms and Abbreviations

EC	European Commission
EU	European Union
PA	Project Advisor
PC	Project Coordinator
SC	Steering Committee
TL	Task Leaders
WP	Work Packages
IAM	Integrated Assessment Model



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Introduction

This technical report is both a contractual deliverable for WP3.2 – “Update and Upgrade of NEMESIS” of the TWINRD project and a supporting document providing guidelines to potential users of the technological innovation module developed within the project. It does not focus on the specific and relatively straightforward task concerning only NEMESIS, which consisted of extending the number of NACE sectors represented in the model. The list of additional sectors (see Table 5) was obtained by splitting pre-existing “parent” sectors in NEMESIS, based on the FIGARO 2025 release except for the split of the NACE sector C26 – “Electronic goods” achieved based on the R&D and patent data built in the project.

The innovation module developed in the project enables the modelling of R&D investments by industrial sectors across up to 66 categories of green technologies and 23 categories of digital technologies (13 JTAG and 10 WIPO), along with an “OTHER” category grouping all technologies that are neither green nor digital. It is therefore possible to work with up to 90 distinct technologies. The list of green technologies retained (Table 8) is based on an aggregation of the EPO Y02–Y04S classification scheme, while the JTAG (legacy digital, Table 9) and WIPO (new digital, Table 10) classifications are respectively derived from the OECD J-Tag taxonomy and the WIPO 4IR taxonomy.

The code used to generate the innovation module is available in the TWINRD project repository on Zenodo, together with all data and programming tools required for its implementation.

The TWINRD innovation module is implemented in Python and relies on the Pyiode package, developed and maintained by the Federal Planning Bureau (FPB) in Brussels. This package enables the creation of all objects used in macroeconomic models, namely scalars (parameters), variables (time series), and equations. It also includes the IODE simulation tool, which allows the simulation of recursively dynamic multi-sectoral macroeconomic models.

The innovation module also includes additional programming tools specifically developed within the project to facilitate rapid adaptation of the code used to generate scalars, variables, and equations, through intuitive and user-friendly instructions.

The Python code provided to generate the innovation module has been parameterized to work with the 90 technologies identified in the project but the users of the innovation module can customize the number of technologies they wish to work with. The code is also designed to operate with a set of 25 NACE sectors (all manufacturing sectors under Division C, plus sector J62 (“Computer programming”), which plays a key role in both digital and green technologies (see Table 6).

The list of countries retained (Table 7) corresponds to those for which consistent data are available from both FIGARO use tables (2025 release) and business R&D datasets from official sources (see TWINRD Deliverable D2.2 on Zenodo). All EU27 countries are represented individually, along with 10 additional countries outside the EU. A “Rest of the World” (RW) region aggregates all other countries, ensuring full global coverage of the



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innovation module. Both the list of sectors and the list of countries can be customized according to users' needs.

The report is organized as follows:

Section 1 introduces the state of the art of innovation modelling in existing macroeconomic models and presents the rationale for the innovation module dedicated to the twin transition that is being developed in the context of the TWINRD project.

Section 2 describes the work carried out to update the patent, R&D and citation datasets that were published in July 2025 under Deliverables D2.1 and D2.2.

Section 3 presents the general empirical framework followed to develop the TWINRD innovation module and details the data and equations on which it is based. Although the current focus remains on technology production, the general framework for representing technology adoption, which is being developed in WP4, is also presented.

Section 4 informs potential users of the TWINRD innovation module about the volumetry it implies in terms of the number of objects to be created and loaded into their simulation systems, depending on the number of detailed technology clusters they wish to include in their macroeconomic model.

Section 5 provides general guidelines to users of the TWINRD innovation module on the practical ways of linking this module to their own macroeconomic model.

Section 6 concludes and outlines the next steps of the project, including future developments of the innovation module and its extension towards the modelling of technology adoption.

1. Background

The innovation module developed in the TWINRD project, in connection with WP2, WP3 and WP4, was designed to address the lack of representation of technologies involved in the twin transition (green and digital) in existing macroeconomic models.

Before the TWINRD project, a limited number of macroeconomic models for EU countries included an explicit representation of technological change based on R&D investments. These include the QUEST III model (Roeger et al., 2022), an aggregate DSGE model; the RHOMOLO model (Christensen, 2022), a spatial model at the NUTS-2 regional level; GEM-E3 (Capros et al., 2017), with a representation of key clean energy technologies and their value chains; and the macro-econometric model NEMESIS (Boitier et al., 2022).

However, none of these models explicitly represents the different categories of green and digital technologies, nor the synergies between them. Their common approach consists of assuming that sectors invest in R&D to improve their own technology, which is reflected in an increase in Total Factor Productivity (TFP) growth (and, in the case of NEMESIS, also in product quality improvements).

Now, regarding digital technologies:



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- the so-called fourth industrial revolution (4IR) technologies (World Intellectual Property Organization, 2022, and called WIPO thereafter) can be grouped into four main clusters: enabling technologies including cloud computing, 5G, blockchain, augmented/virtual reality; foundational technologies covering measurement & reporting, big data analytics; decision-making technologies: digital twins, AI/ML) and sensing and control technologies corresponding to internet of things, drones & imaging, automation & robotics
- while the earlier digital technologies (Organisation for Economic Co-operation and Development, 2017, referred to as JTAG technologies thereafter), also known as third industrial revolution technologies, form the core technological base upon which newer digital technologies have developed. They encompass all technologies related to the production, use, transmission, and storage of digital information, including hardware, software, and databases.

Digital technologies contribute to decarbonisation in multiple ways: by improving efficiency in carbon-intensive processes, promoting energy-saving solutions (e.g. smart appliances and smart meters in buildings), and facilitating the deployment and management of renewable energy systems (e.g. smart grids). However, digital technologies have environmental costs, as they are energy- and resource-intensive, generate waste, and may increase overall energy demand.

These interdependencies between green and digital transitions are now widely recognized in both academic literature (Fouquet & Hippe, 2022) and policy discussions. However, there have been no significant attempts to represent them explicitly in macroeconomic modelling or in empirical economic analysis. One key reason is the insufficient integration of R&I activities into macroeconomic models, despite the fact that R&I and knowledge spillovers are major drivers of cost reductions and accelerated diffusion of green and digital technologies. Prior to the TWINRD project, no existing model provided a robust and explicit representation of the economic sectors developing these technologies.

The overarching objective of the TWINRD project is therefore to develop new modelling approaches and enhance existing macroeconomic models used to evaluate R&I policies and their impacts on key socio-economic and environmental indicators. To this end, TWINRD develops, within its Work Packages 2, 3, and 4, innovative methods for representing R&I investments and policies across EU-27 countries and other world regions, which can be implemented in a wide range of applied macroeconomic models.

2. Updating patent, R&D and patent citations datasets

The TWINRD project's output aims to support the characterization and macroeconomic modelling of key green and digital technologies at a highly detailed geographical and sectoral level. To do so, the project produces (within WP2, WP3, and WP4) beyond state of the art and open access data, inputs, and programming tools usable by the macro-modelling community and contributing to the macroeconomic impact assessment of R&I policies capacity.



These datasets are designed to respond to the need identified in the literature better linking innovation indicators (R&D, patents and citations) with macroeconomic modelling frameworks, to capture knowledge spillovers and technological complementarities across sectors and countries. These datasets have been released in July 2025 (see D2.1 and D2.2 for details) and have been published open-access in Zenodo. Three major datasets are concerned:

- Patent counts- number of patent families (UNU-MERIT, 2025a)
- Business R&D investments- in € million (Le Mouél et al., 2025)
- Knowledge flow matrices- based on patent citation data (UNU-MERIT, 2025b)

These datasets were produced for a set of 45 countries, 25 economic activities, following the NACE rev2 of which 24 manufacturing sectors plus “Computer programming”, J62; 23 digital technologies of which 13 JTAG and 10 WIPO; and 14 different categories of green technologies. However, these datasets presented several difficulties for their integration into macroeconomic models, in particular:

- While patent counts and technology flow matrices were designed to identify “twin” patents i.e. patents classified simultaneously as green and digital, this was not the case for the R&D dataset, which did not identify R&D investments targeting combined green and digital technologies.
- The level of granularity of the green technology categories, 14 broad categories corresponding to the main classes of the EPO Y02–Y04S scheme, even if already relatively detailed, macroeconomic modelling needs and in particular for mitigation action, require even more granular green technologies.
- Raw data on patent, R&D, and technology flow data combining country, sector and technology group levels may contain missing or empty values or for a given year while available for some others. This lack of continuity made the datasets difficult to use in applied macroeconomic modelling.
- R&D data cover 45 countries of which the major R&D contributors however there is not a “Rest of the World” region ensuring a global coverage.
- In some cases, it exists inconsistencies between datasets. Some country, sector and technology combinations of patent data can exist while similar combination for R&D data or citation data do not.

In response to these shortcomings, updated versions of the dataset were developed after July 2025 with the following improvements

- The number of green technologies was extended from 14 to 66, providing a much higher level of detail within the EPO Y02–Y04S classification.
- The R&D dataset has been re-designed to account for all possible combinations of technologies ($2^3 = 8$).



- The geographical coverage of patent, R&D and citations data was adjusted to ensure consistency with the FIGARO use tables (2025 edition), including full global coverage.
- Time series for patent and R&D data were consolidated by implementing intra-, inter- and extrapolation methods, ensuring continuous series over the period 2000–2021.
- Dataset have been processed to remove all inconsistent combinations i.e. combinations of country, sector, technology, and technology group not all represented at the same time across patent, R&D, and citation datasets.

The final patent and R&D datasets are structured along four dimensions:

- **c** = country (1 to 41)
- **s** = sector (1 to 25)
- **t** = technology (1 to 90)
- **k** = technology group (1 to 8, representing combinations of technologies)

Regarding technology combinations, eight possible configurations are defined (Table 1).

Table 1: List of existing technologies combinations

GREEN	JTAG	WIPO	Code	Label
0	0	0	G0-J0-W0	Others: No Green, JTag, or WIPO techno involved
0	0	1	G0-J0-W1	WIPO only: Emerging or advanced digital tech
0	1	0	G0-J1-W0	JTag only: Existing ICT/JTag technology
0	1	1	G0-J1-W1	JTag + WIPO: Both ICT and emerging digital tech
1	0	0	G1-J0-W0	Green only: Environmentally beneficial tech
1	0	1	G1-J0-W1	Green + WIPO: Both Green and emerging digital tech
1	1	0	G1-J1-W0	Green + JTag: Both Green and ICT/JTag technology
1	1	1	G1-J1-W1	Green + JTag + WIPO: All three categories involved

Each technology is assigned uniquely to a combination. For instance, a technology may be classified as “Green only” (EPO classification only), “Jtag only”, or “pure WIPO only”, or belong to combinations such as “Green + Jtag”, “Green + WIPO”, or “Green + Jtag + WIPO”. The category (0,0,0) groups all technologies that are neither green nor digital.

Table 2 presents all possible combinations of indices (c, s, t, k) and their associated number of objects in a theoretical full dataset.

For illustration, assuming that all the 25 sectors for all the 41 countries were active across all technologies and technologies combinations, this would result in 308,525 possible R&D series ($c \times s \times t \times k$ combinations).

In practice, the datasets could therefore potentially include:

- 308,525 time series for patent and R&D time series over the period 2000–2021
- More than 67.24 million objects for citation matrices in the $(c, s, k) \times (c, s, k)$ dimensions



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Table 2: Maximum number of objects involved in the TWINRD innovation module

	c	s	t	k	c,s	c,t	s,t	c,s,t	c,s,k	c,s,t,k	c,s,k x c,s,k	c,s,t,k x c,s,t,k
Number:	41	25	66	4	1025	2706	1650	67650	4100	270600	1.681E+07	7.322E+10
Number:	41	25	13	2	1025	533	325	13325	2050	26650	4.203E+06	7.102E+08
Number:	41	25	10	1	1025	410	250	10250	1025	10250	1.051E+06	1.051E+08
Number:	41	25	1	1	1025	41	25	1025	1025	1025	1.051E+06	1.051E+06
Total number:	41	25	90	8	1025	3690	2250	92250	8200	3.085E+05	6.724E+07	9.519E+10

If citation matrices had been constructed with all complete dimensions, the $(c, s, t, k) \times (c, s, t, k)$ combination would have resulted in more than 95.1 billion objects. As this will not be manageable, citation matrices were instead constructed at the (c, s, k) level and thereafter projected onto the (c, s, t, k) dimension using proxies based on R&D shares.

Importantly, the actual number of combinations present in the dataset is much smaller than the theoretical maximum. In practice, only a limited subset of (c, s, t, k) combinations is not null, that significantly reduces the number of objects to be handled in the modelling.

This reduction in the number of objects to deal with has been enhanced through data filtering procedures, as such:

- Patent and R&D data series for which no value exists for at least two years over a given reference period (2016_2021) have been removed. This reduced the amount of series by approximately 70%, while affecting less than 0.5% of total patent counts and total R&D expenditures.
- Ensuring by in-depth controls that this filtering did not disproportionately exclude small countries or emerging technologies, particularly for early-stage WIPO digital technologies.
- Removing all observations for variables not existing at the same time in the patent and R&D datasets.
- Citation flows that did not correspond to existing (c, s, k) combinations in the final R&D dataset.



Table 3: Actual number of objects present in the datasets and used in the modelling

CITATIONS dataset (in standard classification)	
67 240 000	<— Cartesian space of keys across the 6 dimensions (41C × 25S × 8 CT) ^2
3 282 763	<— Rows CITED (41 countries × 25 NACE codes × 8 "CT") X CITING (41 countries × 25 NACE codes × "CT")
4.88%	<— Ratio of observed of citations to total possible combinations (Cartesian product)
2521920	<— Patent citations effectively used, as they can be linked to R&D data
PATENTS dataset (in standard classification)	
308525	<— Cartesian space of keys across the 4 dimensions (41C × 25S × (89T × 7 CT + 1T))
92505	<— Time series (NB: incomplete series may contain NaN values)
6141975	<— Patent families
27956	<— Time series after filtering (- 70%)
6114965	<— Patent families after filtering (- 0,44% over the last 6 years: 2016–2021)

Finally, beyond patent, R&D, and citation data, additional indicators are required for the functioning of the innovation module, such as R&D, knowledge, and innovation stocks. Nevertheless, the substantial reduction in the size of the initial datasets makes it possible to model at least the 90 individual technologies considered in TWINRD within existing macroeconomic modelling frameworks, while maintaining computational feasibility.

3. General framework of the TWINRD's innovation module

The innovation module developed within the TWINRD project is an operational tool for modelling green and digital technologies at a highly detailed level. It can be implemented in any existing macroeconomic model.

In comparison with existing macroeconomic models that already endogenize technological change, the main improvement of the TWINRD module lies in its ability to represent innovation not only at sector level, but also at the green and digital technologies level, in which sectors invest across countries. Moreover, interactions between green and digital technologies are explicitly modelled.

Beyond representing R&D investments by firms and sectors in the development and production of new technologies, the innovation module also incorporates a modelling framework for the adoption of technologies and their economic impacts.

To better capture these two dimensions —on the one hand, the production of technologies, and on the other hand, their adoption— Figure 1 provides a schematic representation of the modelling structure.

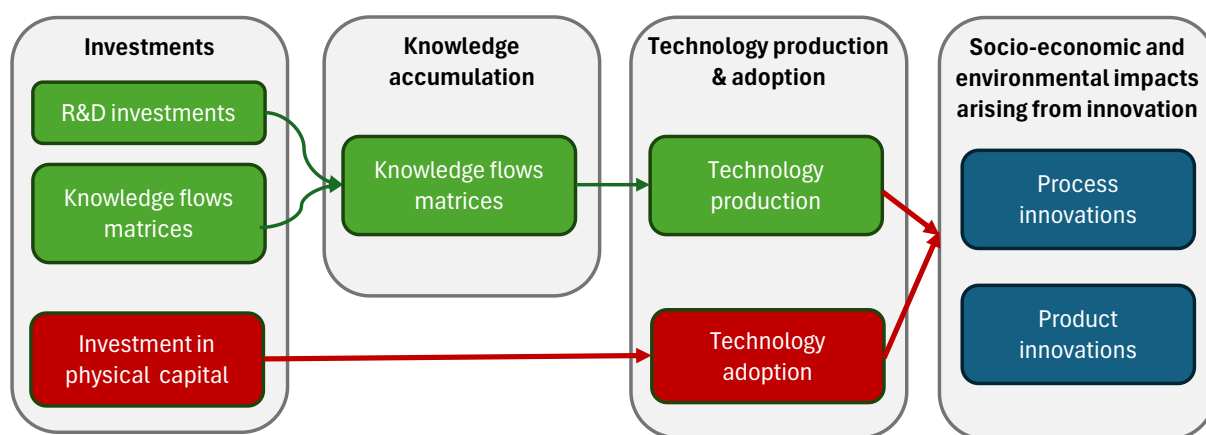


3.1. Production and adoption of technologies

The green part of the Figure 1 shows the conceptual modelling framework through sequential steps starting from R&D investments and leading to productivity improvement and increasing demand for innovative sectors. The combination of R&D data with patent citation matrices allows the construction of knowledge stocks for each technology within a given sector and country. These knowledge stocks lead to inventions, which are then industrialized through production capacity: investments in physical capital, labour and intermediate inputs. This part of modelling chain corresponds to the developments carried out under WP3.2 of the TWINRD project.

The second part of the modelling framework, in red at the bottom of Figure 1, describes the adoption of technologies by the economic activities. The adoption of new technologies — whether green, digital, or “twin” (both green and digital)— occurs through investments in physical capital that embody these technologies. On the adoption side, the distinction is made between (i) specialised (applied) technologies, typically green or twin technologies —which are sector-specific (e.g. photovoltaic technologies used in electricity generation)— and (ii) generic (enabling) technologies, typically digital technologies —which are pervasive and support innovation across a wide range of sectors (e.g. artificial intelligence). The measurement and representation of pervasive technologies across the whole economic activities, as digital technologies is inherently more complex and necessitates the calculation of indicators that captures for each sector, the technological content of different capital assets. This is a work is currently under development in WP4.

Figure 1: The production and the adoption of digital and green technologies in the TWINRD's innovation module



In green: work done in T3.2; in red: ongoing work in WP4 and in blue: specific to the macroeconomic model in use.

3.2. Linking production, adoption and impacts

In the TWINRD innovation module, the production and adoption of technologies will be combined later in the project at WP4 using CES (Constant Elasticity of Substitution) functions. Through this mechanism, both processes contribute to improvements in productivity and demand, as well as to broader impacts such as changes in material use and greenhouse gas

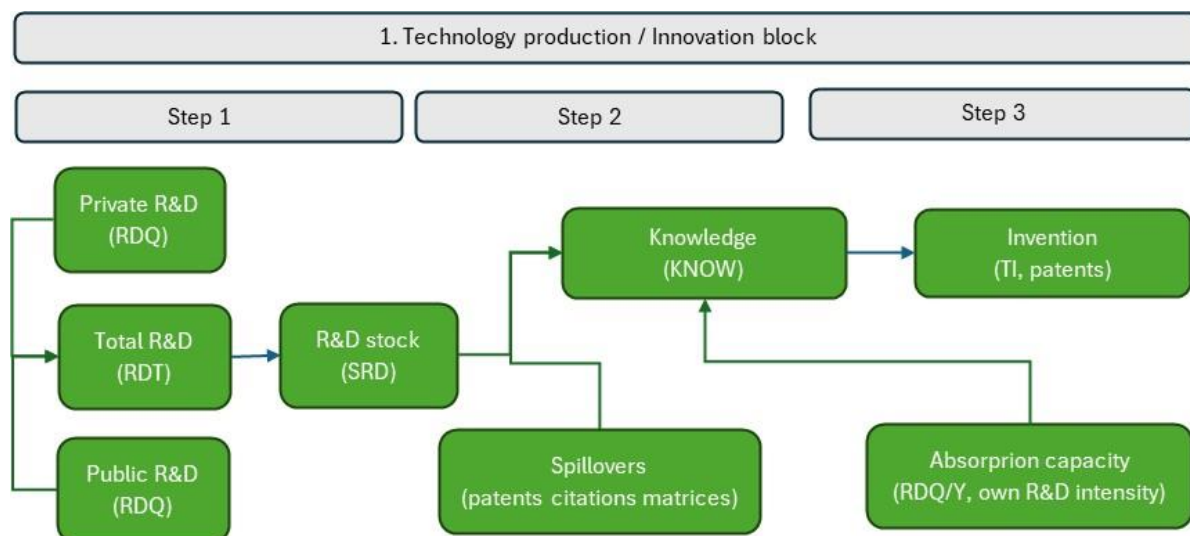
(GHG) emissions. These impacts are represented in Figure 1 —blue elements on the right-hand side— however, here, the precise transmission mechanisms between technological development and socio-economic or environmental outcomes depend on the macroeconomic model in which the innovation module is implemented.

Diagram 1, Diagram 2 and Diagram 3 provide a detailed representation of the modelling framework introduced above.

3.2.1. From R&D investment to inventions

Diagram 1 details the production chain of new technologies (upper green part of Figure 1). It begins with R&D investments by countries and sectors, investment disaggregated by technologies and technology combinations and realized by the private sector (*RDQ*) and/or by the public sector (*RDQ*). Both flows generate the total R&D (*RDT*) that is accumulated overtime in a stock (*SRD*) with time lags and annually depreciated at a fixed rate. In a second step, R&D stocks are combined with patent citation matrices (see UNU-MERIT, 2025b) which capture knowledge spillovers between countries, sectors, and technologies. Finally, the R&D effort of a sector—measured by its R&D intensity (R&D expenditure relative to output)—determines the flow of inventions for a given technology. From this, a stock of innovations is also constructed.

Diagram 1: From R&D investment to inventions



3.2.2. From investment in physical assets to technology adoption

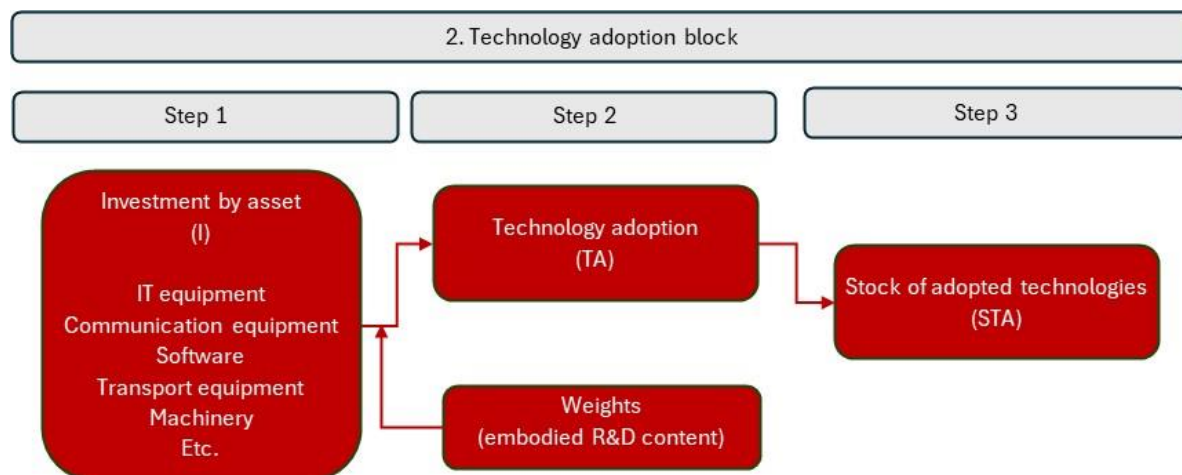
Diagram 2 details the adoption sequential chain (lower red part in Figure 1). It starts with investments in physical assets, which are typically classified into five categories (by excluding investments in building and other infrastructures):

- information technology (IT) equipment
- communication technology (CT) equipment
- software

- transport equipment
- machinery

The technological content of these categories of assets is derived for each country and sector from input-output tables at the global level —also named Global Multi-regional Input-Output dataset, such as the FIGARO (Eurostat, 2021). R&D-based weights still on conception are then used to construct composite indices of technology adoption. The stock of adopted technologies evolves over time through accumulation and depreciation mechanisms.

Diagram 2: From investment in physical assets to new technologies adoption



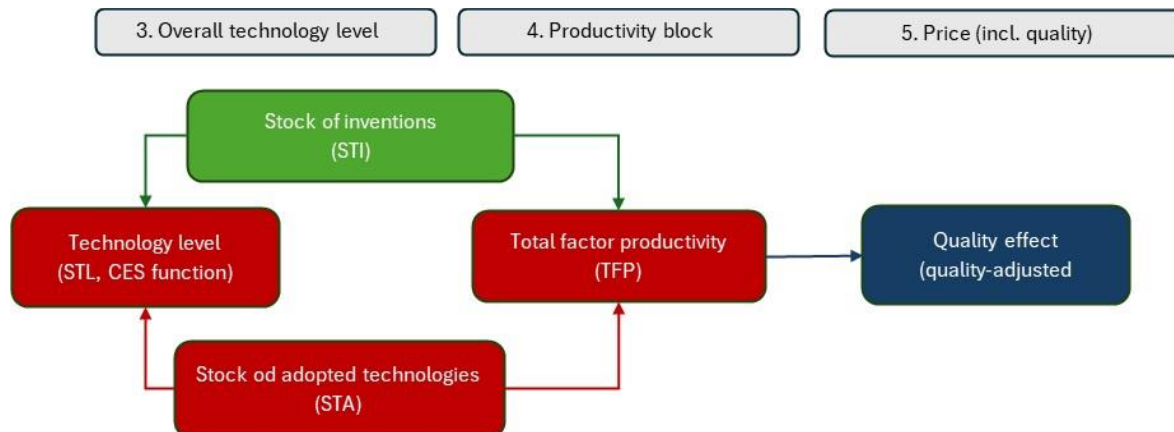
3.2.3. From technology investment to socio-economic and environmental impacts

Diagram 3 describes how investments in technologies—through both production and adoption—translate into socio-economic and environmental outcomes.

The stocks of invented technologies (*STI*) and adopted technologies (*STA*) are combined into a technology level indicator (*STL*) using a CES aggregation function. This indicator affects sectoral productivity with impacts calibrated on existing empirical literature. In the case of the NEMESIS model, quality effects are also considered: improvements in technology reduce production prices not only through productivity gains but also through increases in product quality; prices are then quality-adjusted.

The general framework described in these diagrams may vary depending on the type of technology. In particular, green technologies may have direct impacts on environmental indicators (e.g. GHG emissions), whereas digital technologies tend to have more indirect effects. This distinction between production and adoption is particularly important in the context of the twin transition. While the current version of the innovation module focuses on the production of technologies through R&D investments, the adoption and diffusion of these technologies across sectors remain key drivers of their macroeconomic and environmental impacts. The integration of adoption mechanisms, including the role of digital technologies as enabling factors for green technologies, constitutes a major extension —currently under development within WP4.

Diagram 3: From investing in new technologies to socioeconomic and environmental impacts



4. TWINRD's innovations module: variables, parameters and equations

This section details the different objects—namely variables, equations, and parameters—included in the TWINRD innovation module.

At this stage, the module represents the production chain of technologies (upper green part in Figure 1), i.e. from R&D investments to the direct socio-economic impacts on the sectors that invent, develop, and produce new technologies.

This modelling structure provides a consistent representation of the innovation process, from R&D investments to knowledge creation and invention outputs, which is often missing in traditional macroeconomic models where innovation is represented in a highly aggregated manner.

24 manufacturing sectors (including IT services) are concerned by this innovation framework—see Table 6 for the detailed list—and for the other sectors, mainly services, the impacts of new technologies are transmitted through the input-output structure of the macroeconomic model. These impacts arise from price reductions in intermediate and investment goods driven by productivity gains and quality improvements in industrial sectors.

This general innovation framework was already in application in macro-economic models, prior to the TWINRD project, however, now it is extended to account for up to 89 green and digital technologies as well as an “OTHER” category grouping neither green nor digital technologies.

4.1.1. Flexibility in technology selection

The innovation module has been designed to allow users to select their own set of technologies, subject to the constraint of including the four main technology groups (OTHER, JTAG, WIPO, and Green) must be included. The minimum number of technology category is four—one per group—while the maximum is 90. In case, the technology selection covers a subset of technologies within a group (e.g. one JTAG technology), the remaining technologies



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of the group are aggregated into a residual category (e.g. OTHER_JTAG). Thus, selecting one JTAG, one WIPO, and one Green technology would lead to seven different categories: 3 individual technologies (one per group), 3 residual groups (OTHER_JTAG, OTHER_WIPO, OTHER_GREEN) and the general OTHER category.

4.1.2. Dimensional structure of the module

Variables and equations of the innovation module are presented below and summarized in Table 4. It includes 9 variables —without accounting for the country, sector, technology and technology group dimensions— and 7 equations while parameters are directly embedded in equations for trackability.

In a first step, from R&D to R&D stocks, the module generates R&D-related variables for the selected (c, s, t, k) combinations where c is the country/region (up to 41, including the “Rest of the World”), s : the sector or economic activity (up to 25), t : the technology (from 4 to 90) and k : the technology group (8). Two variables: the private R&D investment ($RDQ_{c,s,t,k}$), representing private R&D expenditures and the public R&D investment ($RDp_{c,s,t,k}$), representing public R&D expenditure attributed to sector s^2 that are input variables in the module, are summed to calculate the total R&D expenditure ($RDt_{c,s,t,k}$). Both private and public R&D investments are used to calculate the stocks of private ($SRDQ_{c,s,t,k}$) and of public R&D ($SRDP_{c,s,t,k}$), with the perpetual inventory method, and applies two different depreciation rates: 0.15 for private and 0.05 for public R&D stock —usual standard values used in the NEMESIS model and in the literature (see e.g. Griliches, 1979). While the total R&D stock ($SRDT_{c,s,t,k}$), the one used thereafter, for the knowledge stock calculation, is a time-lagged sum of both R&D stocks: private (2 years) and public (4 years) —reflecting delays between expenditure and usable knowledge.

In a second step, from R&D stocks to knowledge, the knowledge stock ($KNOW_{c,s,t,k}$) is computed using patents citation matrices that capture knowledge spillovers across countries, sectors, technologies, and combination of technology. Patent citations variables³ ($CIT_{c,s,t,k,c_1,s_1,t_1,k_1}$) denotes the “weighted” number of citations from (c_1, s_1, t_1, k_1) to (c, s, t, k) . This formulation captures international, inter-sectoral, and inter-technology knowledge spillovers. Here, the values of coefficients of the patent matrices are directly embodied in equations allowing to significantly reduce the size of the equations, which is critical given the potential number of parameters (see Table 3).

In a third step, the flow of inventions ($TI_{c,s,t,k}$) is modeled as a function of the growth of the knowledge stock, weighted by the sector’s capacity to absorb this incoming knowledge. This absorptive capacity is proxied by the sector’s own R&D intensity. Consequently, for a given increase in knowledge received by a sector, higher R&D investment enhances its ability to

² In the current version of the module, this variable is set to zero and will be updated in future developments (WP4)

³ Even if citation data produced in the project have initially no t and t_1 dimensions we have used a methodology to overcome that (from the share of respectively t ’s R&D in k ’s R&D and of t_1 ’s R&D in k_1 ’s R&D).



translate this knowledge into a larger number of inventions, ultimately leading to higher productivity and/or quality-adjusted production.

Table 4: Summary of innovation module variables and equations

Steps	Variable name	Variable code	Variable equation
From R&D to R&D stocks	Private R&D investment	$RDQ_{c,s,t,k}$	
	Public R&D investment	$RDp_{c,s,t,k}$	
	Total R&D	$RDt_{c,s,t,k}$	$RDQ_{c,s,t,k} + RDp_{c,s,t,k}$
	R&D stocks	$SRDQ_{c,s,t,k}$ $SRDP_{c,s,t,k}$ $SRDT_{c,s,t,k}$	$SRDQ_{c,s,t,k} = (1 - 0.15) * SRDQ_{c,s,t,k}[-1] + RDQ_{c,s,t,k}$ $SRDP_{c,s,t,k} = (1 - 0.05) * SRDP_{c,s,t,k}[-1] + RDp_{c,s,t,k}$ $SRDT_{c,s,t,k} = SRDQ_{c,s,t,k}[-2] + SRDP_{c,s,t,k}[-4]$
From R&D stocks to knowledge	Weighted number of patent citations	$CIT_{c,s,t,k,c_1,s_1,t_1,k_1}$	
	Knowledge stock	$KNOW_{c,s,t,k}$	$KNOW_{c,s,t,k} = \sum_{c_1,s_1,t_1,k_1} CIT_{c,s,t,k,c_1,s_1,t_1,k_1} * SRDT_{c_1,s_1,t_1,k_1}$
From knowledge to inventions	Production	$Y_{c,s}$	
	Private R&D intensity	$IntRD_{c,s}$	$IntRD_{c,s} = \frac{RDQ_{c,s}}{Y_{c,s}}$
	Flow of inventions	$TI_{c,s,t,k}$	$TI_{c,s,t,k} = dln(KNOW_{c,s,t,k}) * IntRD_{c,s}[-2]$
	Stock of inventions	$STI_{c,s,t,k}$	$STI_{c,s,t,k} = (1 - 0.15) * STI_{c,s,t,k}[-1] + TI_{c,s,t,k}$

Variable in purple indicate they are required input variables of the module, in orange, are indicated variables with equations. Number in square brackets indicate the yearly time-lagged of the variable.

4.1.3. State-of-play and future developments

The TWINRD innovation module is operational and represents a major improvement over existing macroeconomic models in terms of technological detail. However, further developments are ongoing, particularly regarding (i) alternative specifications of knowledge and invention equations avoiding the use of patent data and (ii) the integration of technology adoption (WP4). Once integrated into a macroeconomic model, the module can generate additional indicators related to technology production such as the employment or material and energy content, the GHG emissions and the trade by technology. These extensions will be documented in future work under WP4.



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5. The volumetry of the innovation module

The TWINRD innovation module delivered on Zenodo was first generated using a simplified configuration with only 7 technology clusters (two for JTAG, two for WIPO, two for Green, and one for the OTHER category). This configuration was used for testing and debugging purposes.

The module was subsequently generated with 90 technology clusters detailed in the project, including all 13 individual JTAG technologies, all 10 individual WIPO technologies, 66 clusters of green technologies, and the OTHER category.

This default configuration enables a detailed representation of all green and digital technologies included in the project.

This section provides an overview (see Table 11) of the total volumetric requirements of the innovation module in terms of the number of variables and equations to be included in a macroeconomic model.

The results show that increasing the number of technology clusters from 7 to 90 leads to a substantial increase in the number of variables and equations, although this increase is not strictly proportional. While the number of technologies increases by a factor of approximately 13, the total volumetry increases about 3 times, with respectively a rise from 101,582 to 323,267 for the number of variable and from 95,592 to 299,664 for the number of equations.

Therefore, generating the full set of 90 technologies leads to a number of time series and equations that remains compatible with the computing capacity of modern laptops equipped with 16 or 32 GB of RAM.

6. TWINRD's innovation module: guidelines to its implementation in a macroeconomic model

The main difficulty encountered during the development of the TWINRD innovation module was the very large size of the datasets, which required a modelling approach based on discrete keys. Only the combinations of indices (countries, sectors, technologies, and technology groups) that actually exist are represented, rather than using full Cartesian products as in traditional macroeconomic modelling. As a result, the main challenge for users lies in their ability to handle variables and equations that exist only for a limited subset of countries, sectors, or technologies. This depends on the capabilities of the modelling software used.

The innovation module itself relies on the open access python package `pyiode`⁴, which enables the creation of model objects: variables (time series), equations and parameters and the use of the model solver. In practice, the innovation module presented above is generated with this `pyiode` package and can be also used to connect any macroeconomic model. However, the key conceptual question is: how to connect the innovation indicators produced by the module to the macroeconomic model.

⁴ <https://github.com/plan-be/iode>



In NEMESIS, as well as in the TWINRD model developed under WP4, innovation affects the economy through two main channels process innovation and product innovation. Innovations typically arise from the production of new varieties of intermediate and final products and have two main effects on the sectors that produce them:

- They increase productivity through the integration of more advanced equipment and improved technological knowledge (process innovation).
- They lead to the creation of new products or improvements in the quality of existing ones (product innovation).

Starting from the technology level of a sector s in country c ($STL_{c,s}$) and defined as the stock of inventions over technologies t and combinations k , ($\sum_t \sum_k STL_{c,s,t,k}$), see Table 4 for the equations of $STI_{c,s,t,k}$, we can calculate the impact on productivity as such:

$$dln(TFP_{c,s}) = \beta * dln(STI_{c,s})$$

Where, β is a positive parameter depending on the R&D intensity of the sector. Its calibration is based on empirical literature linking R&D investment to TFP growth (see Kancs et Siliverstovs, 2016, for an encompassing study on this topic), with an average elasticity of approximately 0.1. In practice, β is calibrated as a function of R&D intensity using the following homographic function:

$$\beta = coeffinnov * \frac{IntRD_{c,s}}{IntRD_{c,s} + 0.075 * (1 - IntRD_{c,s})}$$

Where *coeffinnov* is a scaling parameter (typically set to 0.5).

Beside direct impact on productivity (process innovation), a second impact of the innovation concern the quality-adjusted impact on prices, that can be modelled using the α elasticity defined as such: $\alpha = (1 + m) * \beta_i$, where m captures the strength of quality effects, and set to -1 when no quality effect is assumed.

Thus, adding productivity and quality effects leads to the final relationship for prices:

$$dln(P_{c,s}) = (2 + m) * \beta * dln(TFP_{c,s})$$

With this formulation, the innovation reduces production prices through two channels, the productivity gains (reducing input requirements per unit of output) and the quality improvements (quality-adjusted prices). Together, these effects drive competitiveness and demand for innovative sectors.

7. Conclusions

This deliverable presents the development and implementation of an innovation module dedicated to the modelling of green and digital technologies within the NEMESIS framework and other existing macroeconomic models.

A major contribution of this work lies in the explicit representation of a wide range of technologies—up to 90 green and digital technologies and their combinations—at a detailed country and sectoral level. Compared with the existing state of the art in macroeconomic



modelling, this represents a significant step forward, as most models typically rely on aggregate representations of technological change through total factor productivity (TFP) or stylised R&D mechanisms.

The module developed in this deliverable introduces a structured modelling chain linking:

- R&D investments (public and private),
- knowledge creation through spillovers (via citation matrices),
- and the generation of innovations (measured through invention flows and stocks).

This approach allows capturing key features of innovation processes, including cross-country and cross-sectoral knowledge spillovers, interactions between green and digital technologies, and the role of R&D investments in driving technological change.

At the same time, the work carried out has highlighted important methodological and data-related challenges. In particular, the high level of technological disaggregation required substantial efforts in data construction, harmonization, and completion as well as the development of new modelling tools based on discrete keys. These challenges were successfully addressed, resulting in a fully operational innovation module compatible with existing macroeconomic modelling frameworks.

At this stage, the innovation module focuses exclusively on the production of technologies, through R&D investments and knowledge accumulation processes, while the conceptual framework of the TWINRD project includes both the production of technologies, and their adoption and diffusion across the economy. As a result, the impacts of innovation are currently captured for sectors developing and producing the technology primarily through productivity improvements (process innovation) and quality effects on prices (product innovation). However, these two channels spread over every sector and country through the transition matrices (input-output mainly) included in the macroeconomic models.

The modelling of technology adoption, which is essential to fully represent the twin transition, remains under development (WP4). In particular, the integration of digital technologies as enabling factors for the diffusion and efficiency of green technologies is not yet explicitly operational in the innovation module.

The analysis conducted in this report, together with the broader literature and policy review, highlights that the twin transition is characterized by strong interdependencies between green and digital technologies. Digital technologies play a key enabling role in improving the efficiency and reducing the costs of green technologies, facilitating their deployment (e.g. smart grids, energy systems), and enhancing resource and energy management. Conversely, environmental and climate policies influence the direction and nature of digital innovation, for instance by promoting energy-efficient digital infrastructures and applications. Capturing these bidirectional interactions requires modelling frameworks that go beyond traditional approaches and explicitly represent, especially:

- complementarities between different types of capital (green and digital),
- knowledge spillovers across technologies,
- and the role of policies in shaping the direction of innovation.



The innovation module developed in this deliverable provides a first essential step toward this objective, by introducing a detailed operational representation of the production side of innovation.

The next stages of the project will focus on extending and enriching the current framework in several key directions:

A first priority is the integration of technology adoption mechanisms into the modelling framework. This includes the modelling of the incorporation of technologies into different categories of capital goods, but also capturing diffusion dynamics across sectors and countries and accounting for the enabling role of digital technologies in the deployment of green technologies.

A second priority concerns the enhancement of innovation dynamics, through a better representation of time lags between R&D, innovation, and economic impacts as well as potential extensions toward more endogenous representations of R&D investment decisions.

A third area of development relates to the integration of additional economic and environmental dimensions, notably material and energy use associated with technologies, GHG emissions, employment and skills implications and international trade and value chain effects.

Finally, further work will aim at improving the representation of policy interactions, in particular R&I policies (subsidies, public funding, procurement), regulatory frameworks affecting digital and green technologies, and the combined effects of policy mixes on innovation and diffusion processes.

Overall, the innovation module developed here constitutes a major step forward in the macroeconomic modelling of the twin transition. By enabling a detailed and consistent representation of technological innovation processes, it provides a robust foundation for future developments within the TWINRD project. Together with the integration of technology adoption and the extension of the modelling framework currently in development in WP4 will further enhance its capacity to analyze the full dynamics of the twin transition and to support evidence-based policy evaluation at the European and international levels, that is addressed at the WP5.



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Appendix – Tables and Figures

Table 5: Sectoral split of NEMESIS sectors introduced in the course of the TWINRD project

Initial NEMESIS sector	NACE Rev. 2 split
01 Agriculture	A01 Agriculture
	A02 Forestry
	A03 Fishing
10 Manufactures of chemicals & pharmaceutical products	C20 Manufacture of chemicals and chemical products
	C21 Manufacture of basic pharmaceutical products and pharmaceutical preparations
13 Manufacture of computer, electronic and optical products	C26.1 Manufacture of electronic components and boards
	C26.2 Manufacture of computers and peripheral equipment
	C26.3 Manufacture of communications equipment
	C26.4 Manufacture of consumer electronics
	C26.5 Manufacture of instruments and appliances for measuring, testing and navigation
	C26.6 Manufacture of irradiation, electromedical and electrotherapeutic equipment
	C26.7 Manufacture of optical instruments and photographic equipment
	C26.8 Manufacture of magnetic and optical media
27 Information and communication	J58 Publishing
	J59-60 Motion picture, video, television, broadcasting
	J61 Telecommunications
	J62-63 Computer programming plus informations services
28 Bank, finance, insurance & real estate	K64 Financial services
	K65 Insurance
	K66 Activities auxiliaries to financial services
	L68 Real estate
30 Non-market services	O Public administration and defence; compulsory social security
	P Education
	86 Human health
	87-88 Social work activities



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Table 6: NACE codes used for patent, R&D and citations data in the TWINRD's innovation module

PATENT data	R&D data	Description
["10", "10.5", "11", "12"]	C10_C12	Manufacture of food products; beverages and tobacco products
["13", "14", "15"]	C13_C15	Manufacture of textiles, wearing apparel, leather and related products
["16", "17", "18.1"]	C16_C18	Manufacture of wood, paper, printing and reproduction
["19"]	C19	Manufacture of coke and refined petroleum products
["20.1", "20.2", "20.3", "20.4", "20.42", "20.5", "20.51", "20.6"]	C20	Manufacture of chemicals and chemical products
["21"]	C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
["22", "22.1", "22.2"]	C22	Manufacture of rubber and plastic products
["23", "23.1", "23.3", "23.42", "23.5"]	C23	Manufacture of other non-metallic mineral products
["24", "24.46"]	C24	Manufacture of basic metals
["25.1", "25.2", "25.3", "25.4", "25.5", "25.6", "25.7", "25.9", "25.94"]	C25	Manufacture of fabricated metal products, except machinery and equipment
["26.1", "26.11"]	C261	Manufacture of electronic components and boards (operational definition)
["26.2"]	C262	Manufacture of computers and peripheral equipment (operational definition)
["26.3"]	C263	Manufacture of communication equipment (operational definition)
["26.4"]	C264	Manufacture of consumer electronics (operational definition)
["26.5", "26.51", "26.52"]	C265	Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks
["26.6"]	C266	Manufacture of irradiation, electromedical and electrotherapeutic equipment
["26.7"]	C267	Manufacture of optical instruments and photographic equipment
["26.8"]	C268	Manufacture of magnetic and optical media
["27.1", "27.12", "27.2", "27.3", "27.33", "27.4", "27.5", "27.9"]	C27	Manufacture of electrical equipment
["28.1", "28.11", "28.14", "28.21", "28.22", "28.23", "28.25", "28.29", "28.3", "28.4", "28.9", "28.92", "28.94", "28.95", "28.99"]	C28	Manufacture of machinery and equipment n.e.c.
["29.1", "29.3"]	C29	Manufacture of motor vehicles, trailers and semi-trailers
["30"]	C30	Manufacture of other transport equipment
["31"]	C31	Manufacture of furniture
["32", "32.5", "32.9"]	C32	Other manufacturing
["62"]	J62	Computer programming, consultancy and related activities
["42.2"]	Not Used	Construction of utility projects
["42.91"]	Not Used	Construction of harbours and waterways
["43"]	Not Used	Specialized construction activities



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Table 7: List of countries including RW covered by TWINRD's innovation module

EU27 countries		Other countries (other than EU27)	
Code	Label	Code	Label
BE	Belgium	NO	Norway
BG	Bulgaria	CH	Switzerland
CZ	Czech Republic	UK	United Kingdom
DK	Denmark	AU	Australia
DE	Germany	BR	Brazil
EE	Estonia	CA	Canada
IE	Ireland	CN	China
EL	Greece	IN	India
ES	Spain	JP	Japan
FR	France	KR	South Korea
HR	Croatia	MX	Mexico
IT	Italy	RU	Russia
CY	Cyprus	US	United States
LV	Latvia	Row	Rest of the world
LT	Lithuania		
LU	Luxembourg		
HU	Hungary		
MT	Malta		
NL	Netherlands		
AT	Austria		
PL	Poland		
PT	Portugal		
RO	Romania		
SI	Slovenia		
SK	Slovakia		
FI	Finland		
SE	Sweden		



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Table 8: 66 Green technologies (EPO, 2021) to clusters mapping in TWINRD's innovation module by default setting

Cluster	Technologies
TG01	G_EvT_0_1 — Coastal zones; at river basins
TG02	G_EvT_0_2 — Water conservation; efficient water supply; efficient water use
TG03	G_EvT_0_3 — Adapting or protecting infrastructure or their operation
TG04	G_EvT_0_4 — Adaptation technologies in agriculture, forestry, livestock or agro-food production
TG05	G_EvT_0_5 — In human health protection, e.g. against extreme weather
TG06	G_EvT_0_6 — Technologies having an indirect contribution to adaptation to climate change
TG07	G_EvT_1_1_1 — Air pollution abatement from stationary sources
TG08	G_EvT_1_1_2 — Air pollution abatement from mobile sources
TG09	G_EvT_1_1_3 — Air pollution abatement - not elsewhere classified
TG10	G_EvT_1_2 — Water pollution abatement
TG11	G_EvT_1_3 — Waste management
TG12	G_EvT_1_4 — Soil remediation
TG13	G_EvT_1_5 — Environmental monitoring
TG14	G_EvT_2_1_1 — Wind energy
TG15	G_EvT_2_1_2 — Solar thermal energy
TG16	G_EvT_2_1_3 — Solar photovoltaic (PV) energy



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- TG17** G_EvT_2_1_4 — Solar thermal-PV hybrids
- TG18** G_EvT_2_1_5 — Geothermal energy
- TG19** G_EvT_2_1_6 — Marine energy
- TG20** G_EvT_2_1_7 — Hydro energy
- TG21** G_EvT_2_2 — Energy generation from non-fossil fuels
- TG22** G_EvT_2_3 — Combustion technologies with mitigation potential
- TG23** G_EvT_2_4_1 — Nuclear fusion reactors
- TG24** G_EvT_2_4_2 — Nuclear fission reactors
- TG25** G_EvT_2_5 — Efficient electrical power generation, transmission or distribution
- TG26** G_EvT_2_6_1_1 — Batteries
- TG27** G_EvT_2_6_1_2 — Capacitors
- TG28** G_EvT_2_6_1_3 — Thermal energy storage
- TG29** G_EvT_2_6_1_4 — Mechanical energy storage (e.g. flywheels or pressurised fluids)
- TG30** G_EvT_2_6_2 — Hydrogen technology
- TG31** G_EvT_2_6_3 — Fuel cells
- TG32** G_EvT_2_6_4 — High-voltage direct current transmission
- TG33** G_EvT_2_7 — Other energy conversion or management systems reducing GHG emissions
- TG34** G_EvT_3_1 — Capture or disposal of nitrous oxide (N₂O)
- TG35** G_EvT_3_2 — Capture or disposal of methane (CH₄)
- TG36**



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- TG37** G_EvT_3_3 — Capture or disposal of fluorinated gases
- G_EvT_3_4 — Capture or disposal of carbon dioxide (CO₂)
- TG38** G_EvT_4_1_1 — Conventional vehicles (internal combustion engine)
- TG39** G_EvT_4_1_2 — Hybrid vehicles
- TG40** G_EvT_4_1_3 — Electric vehicles
- TG41** G_EvT_4_1_4 — Fuel efficiency-improving vehicle design
- TG42** G_EvT_4_2 — Rail transport
- TG43** G_EvT_4_3 — Air transport
- TG44** G_EvT_4_4 — Maritime or waterways transport
- TG45** G_EvT_4_5_1 — Electric vehicle charging
- TG46** G_EvT_4_5_2 — Application of hydrogen technology to transportation
- TG47** G_EvT_5_1 — Integration of renewable energy sources in buildings
- TG48** G_EvT_5_2 — Energy efficiency in buildings
- TG49** G_EvT_5_3 — Architectural or constructional elements improving building thermal performance
- TG50** G_EvT_5_4 — Enabling technologies in buildings
- TG51** G_EvT_6_1 — Waste water treatment
- TG52** G_EvT_6_2 — Solid waste management
- TG53** G_EvT_6_3 — Enabling technologies for GHG mitigation
- TG54** G_EvT_7_1 — Technologies related to metal processing
- TG55** G_EvT_7_2 — Technologies relating to chemical industry



- TG56** G_EvT_7_3 — Technologies relating to oil refining and petrochemical industry
- TG57** G_EvT_7_4_1 — Production of cement
- TG58** G_EvT_7_4_2 — Production or processing of lime
- TG59** G_EvT_7_4_3 — Glass production
- TG60** G_EvT_7_4_4 — Ceramic production
- TG61** G_EvT_7_5 — Agriculture, livestock or agro-food industries
- TG62** G_EvT_7_6 — Production process for final industrial or consumer products
- TG63** G_EvT_7_7 — Climate change mitigation technologies for sector-wide applications
- TG64** G_EvT_7_8 — Enabling technologies with potential contribution to GHG mitigation
- TG65** G_EvT_8 — Climate change mitigation in ICT
- TG66** G_EvT_9 — Systems integrating power, communication or ICT technologies



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Table 9: Jtag technologies (OECD, 2017) to clusters mapping in TWINRD's innovation module

Cluster	Technologies
TJ01	J_JTag_1 — High-speed communication networks
TJ02	J_JTag_2 — Mobile communication technologies
TJ03	J_JTag_3 — Information and system security
TJ04	J_JTag_4 — Sensor and device networks
TJ05	J_JTag_5 — High-performance computing systems
TJ06	J_JTag_6 — Large-capacity, high-speed data storage
TJ07	J_JTag_7 — Large-scale data analysis technologies
TJ08	J_JTag_8 — Cognitive computing and semantic understanding
TJ09	J_JTag_9 — Human-machine interface technologies
TJ10	J_JTag_10 — Imaging and audio technologies
TJ11	J_JTag_11 — Communication and information devices
TJ12	J_JTag_12 — Electronic measurement technologies
TJ13	J_JTag_13 — Other ICT technologies



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Table 10: WIPO (2022) technologies to clusters mapping in TWINRD's innovation module

Cluster	Technologies
TW01	W_AI_ML — Artificial intelligence and machine learning systems
TW02	W_BigData — Large-scale data processing and analytics
TW03	W_CloudComp — Cloud-based computing and services
TW04	W_Quantum — Quantum computing, sensing, and timing technologies
TW05	W_AutonmSys — Autonomous and self-operating systems
TW06	W_Robots — Robotic systems and automation
TW07	W_IoT — Connected devices and Internet of Things
TW08	W_SmartCities — Digital technologies for smart cities
TW09	W_Blockchain — Distributed ledger and blockchain technologies
TW10	W_Virt_Aug_Reality — Virtual and augmented reality systems



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Table 11: Number of objects included in TWINRD's innovation module depending on the number of technology clusters selected by the users

	7 technologies clusters		55 technologies clusters		90 technologies clusters	
	# Variables	# Equations	# Variables	# Equations	# Variables	# Equations
PRIVATE R&D						
RDQ_CSTK	6_260	0	20_269	0	23_603	0
RDQ_CST	3_304	3_304	11_370	11_370	14_113	14_113
RDQ_CSK	3_041	3_041	3_041	3_041	3_041	3_041
RDQ_CTK	715	715	3_482	3_482	4_452	4_452
RDQ_CS	847	847	847	847	847	847
RDQ_CT	270	270	1_599	1_599	2_289	2_289
RDQ_CK	279	279	279	279	279	279
RDQ_C	41	41	41	41	41	41
RDQ_EU_STK	300	300	1_225	1_225	1_481	1_481
RDQ_EU_ST	120	120	608	608	815	815
RDQ_EU_SK	122	122	122	122	122	122
RDQ_EU_TK	25	25	158	158	215	215
RDQ_EU_S	23	23	23	23	23	23
RDQ_EU_T	7	7	55	55	88	88
RDQ_EU_K	8	8	8	8	8	8
RDQ_EU	1	1	1	1	1	1
RDQ_WD_STK	382	382	1_983	1_983	2_601	2_601
RDQ_WD_ST	132	132	801	801	1_171	1_171
RDQ_WD_SK	139	139	139	139	139	139
RDQ_WD_TK	25	25	187	187	288	288



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RDQ_WD_S	23	23	23	23	23	23
RDQ_WD_T	7	7	55	55	90	90
RDQ_WD_K	8	8	8	8	8	8
RDQ_WD	1	1	1	1	1	1
PRIVATE R&D Capital Stock						
SRDQ_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
SRDQ_CSK	3_041	3_041	3_041	3_041	3_041	3_041
SRDQ_CS	847	847	847	847	847	847
PUBLIC R&D						
RDP_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
PUBLIC R&D Capital Stock						
SRDP_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
SRDP_CSK	3_041	3_041	3_041	3_041	3_041	3_041
TOTAL R&D (Public + Private)						
RDT_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
RDT_CSK	3_041	3_041	3_041	3_041	3_041	3_041
TOTAL R&D Capital Stock (PUBLIC + PRIVATE)						
SRDT_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
SRDT_CSK	3_041	3_041	3_041	3_041	3_041	3_041
KNOWLEDGE						
KNOW_CSK	3_041	3_041	3_041	3_041	3_041	3_041
KNOW_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
FLOW OF TECHNOLOGY INVENTIONS						
TI_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
TI_CST	3_304	3_304	11_370	11_370	14_113	14_113
TI_CSK	3_041	3_041	3_041	3_041	3_041	3_041



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TI_CS	847	847	847	847	847	847
TI_CTK	715	715	3_482	3_482	4_452	4_452
TI_CT	270	270	1_599	1_599	2_289	2_289
TI_CK	279	279	279	279	279	279
TI_C	41	41	41	41	41	41
TI_EU_STK	300	300	1_225	1_225	1_481	1_481
TI_EU_ST	120	120	608	608	815	815
TI_EU_SK	122	122	122	122	122	122
TI_EU_TK	25	25	158	158	215	215
TI_EU_S	23	23	23	23	23	23
TI_EU_T	7	7	55	55	88	88
TI_EU_K	8	8	8	8	8	8
TI_EU	1	1	1	1	1	1
TI_WD_STK	382	382	1_983	1_983	2_601	2_601
TI_WD_ST	132	132	801	801	1_171	1_171
TI_WD_SK	139	139	139	139	139	139
TI_WD_TK	25	25	187	187	288	288
TI_WD_S	23	23	23	23	23	23
TI_WD_T	7	7	55	55	90	90
TI_WD_K	8	8	8	8	8	8
TI_WD	1	1	1	1	1	1
STOCK OF TECHNOLOGIES (STI)						
STI_CSTK	6_260	6_260	20_269	20_269	23_603	23_603
STI_CST	3_304	3_304	11_370	11_370	14_113	14_113
STI_CSK	3_041	3_041	3_041	3_041	3_041	3_041
STI_CTK	715	715	3_482	3_482	4_452	4_452



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STI_CS	847	847	847	847	847	847
STI_CT	270	270	1_599	1_599	2_289	2_289
STI_CK	279	279	279	279	279	279
STI_C	41	41	41	41	41	41
STI_EU_STK	300	300	1_225	1_225	1_481	1_481
STI_EU_ST	120	120	608	608	815	815
STI_EU_SK	122	122	122	122	122	122
STI_EU_TK	25	25	158	158	215	215
STI_EU_S	23	23	23	23	23	23
STI_EU_T	7	7	55	55	88	88
STI_EU_K	8	8	8	8	8	8
STI_EU	1	1	1	1	1	1
STI_WD_STK	382	382	1_983	1_983	2_601	2_601
STI_WD_ST	132	132	801	801	1_171	1_171
STI_WD_SK	139	139	139	139	139	139
STI_WD_TK	25	25	187	187	288	288
STI_WD_S	23	23	23	23	23	23
STI_WD_T	7	7	55	55	90	90
STI_WD_K	8	8	8	8	8	8
STI_WD	1	1	1	1	1	1
TOTAL	101_852	95_592	276_641	256_372	324_847	301_284



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