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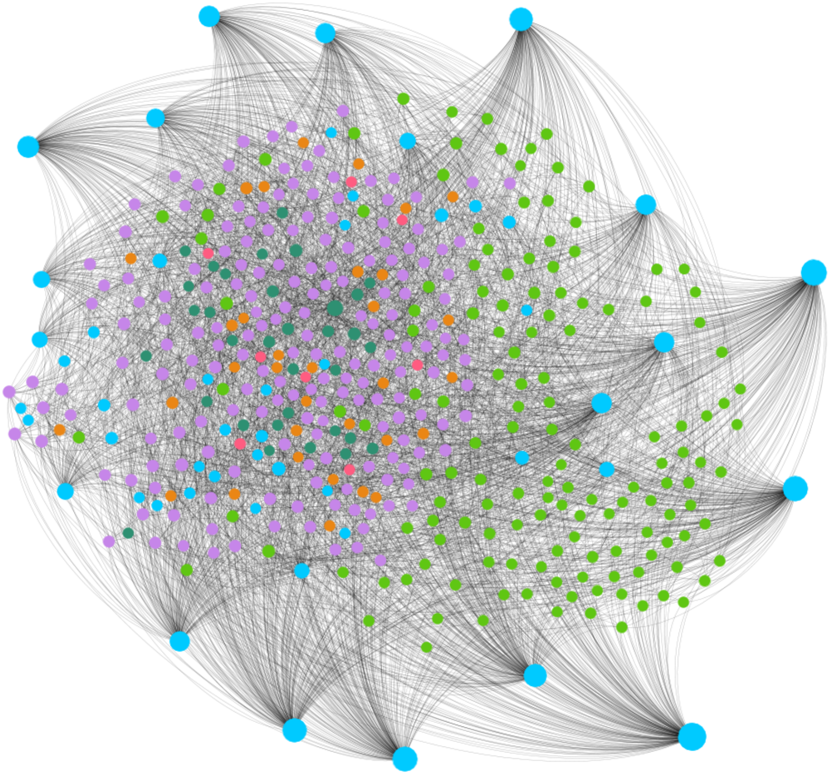

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Lukas Eggler, Andreas Indinger, Lukas Zwieb

Vienna, May 2018

IEA RESEARCH COOPERATION

Programme Sustainable Development

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Preface

This project was initiated by the End-Use Working Party of the International Energy Agency. The End-Use Working Party guides 14 of total 38 Technology Collaboration Programmes (TCPs) and has thematic linkages to several TCPs of the Renewable Energy Working Party and the Working Party on Fossil Fuels.

The intention of this project was to visualize the current activities of the IEA Energy Technology Network and to identify possible gaps and overlaps. It demonstrates a basis for further coordination and collaboration between TCPs and Working Parties.

The mapping includes 185 ongoing projects (tasks, annexes). 35 methods such as type of R&D, standardisation or education are defined and assigned. National R&D budgets of the participating countries are included and can be set in comparison with the engagement in TCPs. This report describes the methodology, selected results and some findings in more detail and enables interested parties to make use of the graph-based database which is provided as open source.

This project was carried out in the Austrian programme „IEA Research Cooperation“ of the Federal Ministry of Transport, Innovation and Technology. It is published on the website **www.nachhaltigwirtschaften.at**, a public service for R&D research results.

Mag. Sabine Mitter
Austrian End-Use Working Party Delegate and Vice Chair

Vienna, June 2018

Abstract

For more than 40 years, the research collaboration programme of the International Energy Agency (IEA) provides a legal framework for international cooperation. Today, about 40 Technology Collaboration Programmes (TCPs) are reporting to three working parties – one for renewables, one for fossil fuels and the third one covering all end use sectors – and one coordination group for nuclear fusion. This management structure provides IEA's Committee on Energy Research and Technology (CERT) with all the necessary information to supervise this part of IEA activities.

CERT and working parties are challenged by the huge amount of horizontal and vertical international cooperations in various topics and sectors. To get a better overview and to identify possible gaps and overlaps, the Austrian Energy Agency (AEA) had been appointed by the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) to gather, analyze and last but not least visualize the relevant data.

Firstly, the existing and publicly available information of the Energy Technology Network itself has been processed. Secondly, the public IEA database for RD&D expenditures/budgets proved complementary and was very valuable for this purpose. In addition to this data, a set of 35 methods has been developed to classify the type of activity carried out. Most of the TCPs are sub-structured in different dedicated activities – eventually 185 of them have been recorded. Linking all the above mentioned data sources into one graph data model resulted in a model with 499 nodes and 5,711 different relationships between these nodes.

The qualitative and quantitative analysis carried out brought some new insights:

- The general focus of activities was clearly on applied research.
- Activities in TCPs provide strong support for policies and legislations, but also testing and standardisation.
- TCPs are very active when it comes to bringing technologies to the market and deploy them.
- There was substantial work on consumer behavior and behavioral change, but no focus on the consumer as the subject (prosumer, privacy issues). No single activity covered data issues (protection of data privacy) as an important aspect of digitalization.
- When covering possible energy policy goals, environmental aspects in general, GHG reduction and last but not least safety and health issues are well covered. But security of supply as a systemic issue is almost not addressed.
- Looking at the end use sectors, there are comparably quite low activities in industry.

The results of this exercise had been presented to and discussed with the End-Use Working Party and the Working Party for Renewable Energy Technologies at their meetings in March 2018. The question was raised if the TCP network has established appropriate communication structures in and between TCPs and working parties to make best use of TCPs' results and public money countries are investing in them. The intention of this report is not only to describe the methodology, selected results and some findings in more detail but to enable interested parties to make use of the graph-based database which is open source. Data was collected and assessed in September 2017.

Kurzfassung

Seit mehr als 40 Jahren bietet die Internationale Energieagentur (IEA) – neben anderen Funktionen – einen Rahmen zur Zusammenarbeit im Bereich der Forschung und Entwicklung. Heute finden diese Kooperationen organisiert in rund 40 Programmen (sogenannten Technology Collaboration Programmes, TCPs) statt. Die Aktivitäten werden vom Komitee für Energieforschung und Technologie der IEA koordiniert, das sich dazu verschiedener Arbeits- und Koordinationsgruppen bedient. Diese Aufgabe ist herausfordernd, da die Zusammenarbeit in weit über 100 Aktivitäten stattfindet, die oft technologie- oder sektorübergreifend agieren. Um einen besseren Überblick zu bekommen und auch mögliche thematische Lücken und Überschneidungen zu identifizieren, wurde die Österreichische Energieagentur vom Bundesministerium für Verkehr, Innovation und Technologie (bmvit) beauftragt, die Daten zu sammeln, zu analysieren und zu visualisieren.

Zuerst wurden die Informationen der Technologieprogramme selbst erhoben. Diese Daten wurden mit den Forschungsausgaben der IEA-Mitgliedstaaten verknüpft, was sich als sinnvoller Schritt herausstellte – lagen diese Daten doch in einer sehr detaillierten thematischen Auflösung vor. In Ergänzung dazu wurde im Rahmen dieses Auftrags ein Portfolio von 35 Methoden entwickelt, mit dem die 185 identifizierten Aktivitäten beschrieben werden konnten. Zusammengeführt wurden alle Daten in einer grafenbasierten Datenbank, die rund 500 sogenannte „Nodes" und über 5.700 „Beziehungsinformationen" ebendieser enthielt. Mit diesen Daten wurden qualitative und quantitative Auswertungen gemacht, die nach eingehender Interpretation auch neue Erkenntnisse brachten:

- Der Schwerpunkt der Aktivitäten liegt im Bereich der angewandten Forschung.
- Die TCPs unterstützen insbesondere Entscheidungsfindungen in der Politik und im rechtlichen Bereich, aber auch die Entwicklung von Tests, Normen und Standards. TCPs sind auch sehr aktiv bei Fragestellungen, bei denen es darum geht, Technologien in den Markt zu bringen und diese dort zu verbreiten.
- Zahlreiche Anstrengungen wurden unternommen, das Verhalten der Konsumentinnen und Konsumenten – und wie dieses beeinflusst werden kann – zu untersuchen. Fast schon ein blinder Fleck blieben jedoch die Möglichkeiten, wo und wie Konsumentinnen und Konsumenten aktiv im Energiesystem agieren können (z. B. als sogenannte Prosumer). Datenschutz – eine zentrale Fragestellung bei der Digitalisierung des Energiesystems – stand jedoch in keiner der 2017 laufenden Aktivitäten im Zentrum.
- Der Industriebereich wurde als derjenige Endverbrauchssektor identifiziert, in dem – gemessen an seinen Forschungsausgaben, aber auch seines Energiebedarfs – vergleichsweise wenig Aktivitäten der TCPs liefen.

Die Ergebnisse wurden den beiden Arbeitsgruppen für Endverbrauch und erneuerbare Energieträger im März 2018 präsentiert und dort diskutiert. Dabei wurde auch die Frage erhoben, ob entsprechende Kommunikationsstrukturen in und zwischen den TCPs und Arbeitsgruppen etabliert sind, um die Ergebnisse – aber auch die investierten öffentlichen Mittel – effektiv zu nutzen. Dieser Bericht beschreibt nicht nur die Methoden und die Ergebnisse, sondern dient auch als Anleitung zur Nutzung der öffentlich verfügbaren Datenbank. Die Daten wurden im September 2017 zusammengestellt und ausgewertet .

Contents

1 Introduction

The first oil price crisis in 1973 was a turning-point in national and international energy policies – for the first time the extent of dependence on the oil-exporting countries was revealed. Consequently the International Energy Agency (IEA) was set up in 1974 as an autonomous entity within the Organisation for Economic Co-operation and Development (OECD), with Austria as one of its founding members.

So for more than 40 years, IEA's research collaboration programme sets the legal framework for international cooperation in the form of Implementing Agreements (IA). This also demonstrates the importance of technology, innovation and R&D to tackle energy security issues.

From 2015 on, the IAs operate under a new name: Technology Collaboration Programmes (TCP). Today, about 40 TCPs are reporting to three working parties – one for renewables, one for fossil fuels and the third one covering all end use sectors – and one coordination group for nuclear fusion. These working parties and the coordination group were established by the Committee on Energy Research and Technology (CERT).

CERT and working parties are challenged by the huge amount of horizontal and vertical international cooperation in various topics and sectors. Substructures eventually emerged to improve coordination. To get a better overview and to identify possible gaps and overlaps, the Austrian delegation in the End Use Working Party offered to carry out comprehensive analysis. The Austrian Energy Agency (AEA) has been appointed by the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) to gather, analyze and last but not least visualize the relevant data. For Austria it was also intended to use the results to check alignment in TCP-participation with national policy priority – a dedicated workshop was carried out in March 2018.

The results of this exercise had also been presented to and discussed with the End-Use Working Party and the Working Party for Renewable Energy Technologies at their meetings in March 2018.

The intention of this report is not only to describe the methodology, selected results and some findings but to enable interested parties to make use of the graph-based database[1] which is provided as open-source.

[1] Note regarding the General Data Protection Regulation (GDPR), effective from 25 May 2018: the database does not include any personalized data.

2 Data, taxonomies and classification

No single data-set serves the needs for this kind of mapping of activities of the IEA Energy Technology Network. So, different sets of data have been identified, linked and analysed. After extensive testing, it was decided to build on two different “families” of information, together with a newly developed methodology.

Firstly, the existing and publicly available information of the Energy Technology Network itself have been processed. Secondly, the public IEA database for RD&D expenditures/budgets proved complementary and was very valuable for this purpose. In addition to this data, a set of 35 methods has been developed to classify the type of activity carried out. All data sources were linked based on publicly available information and expert knowledge.

2.1 The IEA Energy Technology Network

For more than 40 years, IEA’s research collaboration programme sets the legal framework for international cooperation in the form of Implementing Agreements (IA). From 2015 on, the IA operate under a new name: Technology Collaboration Programmes (TCP). Some TCPs terminated during the last decades, some got merged, but others still operate since the starting years of IEA in the mid-seventies of the last century. Also additional challenges – which arose in the decades after the multinational establishment of the IA-System – transformed into new TCPs.

Today, about 40 TCPs are reporting to three working parties (for renewables, fossil fuels end use) and one coordination group for nuclear fusion. These working parties and the coordination group were established by the Committee on Energy Research and Technology (CERT). Work is funded by participants only, and there is a close cooperation with the IEA-secretariat in Paris, which also cares about the legal framework.

Most of the TCPs are sub-structured in projects, called tasks or annexes. In this mapping exercise, all these projects etc. are called “activities”. Eventually 185 activities have been recorded. Publicly available sources like TCP-websites and annual reports have been complemented by the information TCPs provide to their working parties (annual briefs etc.).

TCPs are managed by an Executive Committee (ExCo). For reasons of data structure and processing, each ExCo has been registered as an own activity, too.

For a list of all registered activities, see annex 7.1.

Member States and other countries, together with sponsors, can join a TCP in a dedicated process. After being a member of a TCP, usually each country can participate in activities which are of interest to them. For this mapping exercise, the participation of countries has been identified from available sources. For this purpose, the ISO-Code of countries was applied (see annex 7.5).

2.2 IEA RD&D Statistics

All member countries of the International Energy Agency are obliged to yearly record all energy-related research, development and first-of-a-kind demonstration projects carried out - and which are supported and financed by means of public funds. Alternatively, it is possible to report annual budgets for RD&D.

Table 4
Information on Government Energy RD&D Budgets (A)
Millions, national currency

Years requested: 2014, 2015 estimated and 2016 estimated	**Year**	
One sheet to be filled out for RD&D (excluding state-owned enterprises) and one sheet for state-owned enterprises.	R&D	Demon-stration
BUDGETARY STAGE (see instructions on reporting issues)		
FISCAL YEAR STARTING		
1 **ENERGY EFFICIENCY** (sum of rows 11 to 19)		
11 Industry		
111 Industrial techniques and processes		
112 Industrial equipment and systems		
113 Other industry		
119 Unallocated industry		
12 Residential and commercial buildings, appliances and equipment		
121 Building design and envelope		
1211 Building envelope technologies		
1212 Building design		
1219 Unallocated building design and envelope		
122 Building operations and efficient building equipment		
1221 Building energy management systems (incl. smart meters) and efficient internet		

Figure 2-1: Structure of questionnaire for reporting expenditures/budgets (Source: QUESTIONNAIRE FOR IN-DEPTH ENERGY POLICY REVIEWS 2015-16 CYCLE IEA/SLT (2015)4)

To allocate activities in the field of energy, a categorization with a 4-digit-level is applied. This taxonomy - together with an extensive description of this survey - can be found in the report: IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics (2011). The taxonomy proved suitable to classify the thematic activities of the TCPs for this mapping exercise and is provided in annex 7.3.

As experience in Austria showed, this annual survey is not only an international obligation but also allows emphasising the importance of energy research as well as creating and checking policy goals.

The following treemap[2] shows the overall budget allocation of all IEA member countries.

[2] In a treemap, the area is proportional to a certain value. In this case, it is budget/expenditure in US$

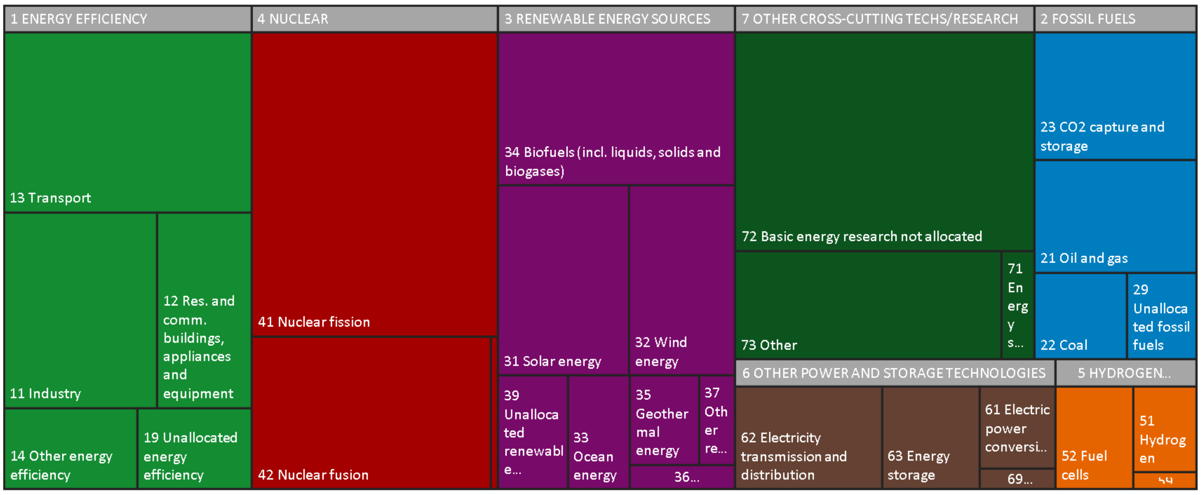


Figure 2-2: Treemap of public energy RD&D spending in 2015 of all IEA-member countries (Data: IEA, processing: AEA)

Because the RD&D budget information is provided for all participating countries it can also be used to analyse different countries RD&D spending characteristics. Figure 2-3 shows energy RD&D budget information for three exemplary countries in form of a sunburst diagram[3]. Note that the size of the sunburst is proportional to the per capita RD&D expenditures and the color code for the seven IEA main topics (Energy efficiency, fossil fuels, renewable Energy, nuclear, hydrogen, other power and storage, other cross-cutting) remains the same as in Figure 2-2 above.

Figure 2-3: Sunburst diagram of public energy RD&D spending per capita for three exemplary countries with significantly different spending characteristics (Austria, USA and Germany). Note that Germany only reports federal expenditures (public expenditures from federal states are not included, resulting in comparatively low per capita expenditures).

The IEA RD&D database can be accessed under the following link: http://www.iea.org/statistics/topics/rdd/

[3] Sunburst diagrams are multilevel pie charts well suited to visualize hierarchical structured quantitative data. The circle in the center represents the root node, with the hierarchy moving outward from the center.

2.3 Methods

Until the start of this exercise, there was no commonly accepted classification available to describe the type of activity. So a set of so called "methods" was developed. A draft-set hat been tested on a sample of around 7 TCPs, modifications led to the final set of 35 methods, grouped in 9 categories (see Table 2-1). Eventually, each of the 185 activities was assigned to up to three different methods (one method as a minimum), based on publicly available information on the activities.

Table 2-1: Table of 35 methods (AEA)

Category	Method	Abbrev.	Number of Activities connected
Administration	Administration	ADMN	20
Available Databases	Best practice	BEST	20
Available Databases	Costs and prices	COST	9
Available Databases	Monitoring	MONI	10
Available Databases	Products	PROD	2
Available Databases	Project database	PROJ	8
Citizen issues	Consumer behaviour and behaviour change	CONS	11
Citizen issues	Big data, protection of data privacy	DATA	0
Communication	Awards	AWRD	4
Communication	Conferences	CONF	7
Communication	Education and training	EDUC	6
Communication	Outreach and raising awareness	OUTR	14
Going to Market	Market introduction	INTR	3
Going to Market	Market development and deployment	MADE	18
Going to Market	Market analysis	MRKT	16
Going to Market	Resource assessment and forecasting	REAS	5
Policies, strategies and facilitation	Energy management systems and audits	EMSA	0
Policies, strategies and facilitation	Planning	PLAN	5
Policies, strategies and facilitation	Policies and legislation	POLE	29
Policies, strategies and facilitation	Roadmaps	ROAD	3
Policies, strategies and facilitation	Standards	STND	19
Policies, strategies and facilitation	Tests (pre-standardisation, testing protocols and product testing)	TEST	26
Policy	Environmental aspects	ENVI	13
Policy	Reduction of GHG	GHGR	5
Policy	Safety and health issues	SAFE	11
Policy	Security of supply	SECS	1
Technology readiness	Applied research	ARES	72
Technology readiness	Basic research	BASC	9
Technology readiness	Cost reduction	CORE	7
Technology readiness	First-of-its-kind demonstration	FOIK	4
Technology readiness	Operational performance	OPER	8
Technology readiness	Technological development	TEDE	15
Tools	Life cycle and technology assessment	LCSA	5
Tools	System analysis and integration	SYST	12
Tools	Modelling and scenarios	SZEN	5

In annex 7.2 there is a short definition of all methods.

2.4 Assumptions and Limitations

Due to limited time, budget and/or available robust information some assumptions had to be made:

1. Nuclear and fusion topics were out of scope of this study, so all TCPs dealing with fusion have been recorded as one single activity.
2. Some tasks report to more than one TCP (so called joint tasks). For this exercise such activities were assigned to only one TCP (the TCP with the more obvious link).
3. Because it was not possible to classify the extent of work, budget and resources of single activities (no detailed information on activities and their budgets available) all activities are weighted equally. In reality this simplification will lead to slightly biased results, as some tasks/annexes are much more active than others.
4. No differentiation of member states, associated countries, partner countries etc. has been made.
5. No sponsors (a type of participation in a TCP for non-governmental bodies) have been processed.
6. The role of the EU or European Commission is quite complex and diverse in TCPs. So the role of EU/EC could not be appreciated concisely and properly.
7. Data was collected and assessed in September 2017. No further updates have applied.
8. Only ongoing and planned activities were collected.
9. In cases were data from different sources showed deviations (e.g. participating countries), the most recent publication was taken into account

It has to be stated, that in principle these assumptions could be avoided in further exercises – if time, budget and access to information allow. For the proper quantification of activities, new procedures and reporting would have to be established.

3 Principles, Platform and Tools

3.1 Graph Database – Basic Principles

In computing a database is a form of organized data collection. Besides being a secure form of data storage, the underlying idea behind a database is to enable the accessibility of the data and its inherent information. The database is managed by a (generic or specialized) database management system (DBMS). This DBSM allows users to interact (e.g. defining, updating and querying) with the database in an easy and comfortable manner.

Today most DBs store the data and the respective meta-information in linked tables (Relational Database). These links between the tables are based on keys (e.g. indices), and allow complex functions (such as joins), which include more than one table.

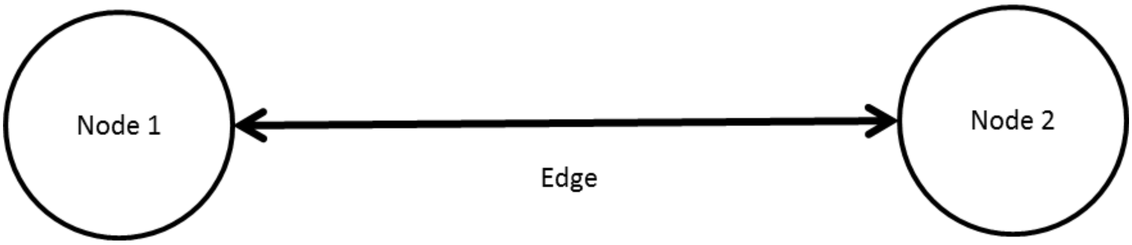


Figure 3-1: Basic concept of a graph: Two nodes are connected by an edge

In contrast to the relational database a graph database employs nodes, edges and properties instead of tables to represent and store the data (see NoSQL). This concept is based on the general graph theory. Figure 3-1 illustrates this concept. A node describes a single entity respectively an object of the dataset. In other words a node describes a single observation, with all its properties. An edge describes the relation that links two nodes. This link can represent different kind of relationships. Typical types of relationships between two nodes are ‘knowing’, ‘owning’ or ‘funded’. As a simple memory aid the construction of small sentences can help to understand or develop a new graph model (compare Figure 3-2).

Pattern: **Subject** (Node1) **verb** (edge) **object** (Node2).

Example: *John knows Karen.*

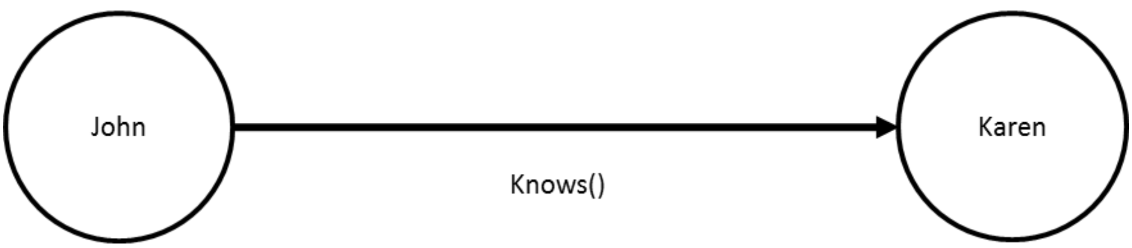


Figure 3-2: Basic example of a graph representing the relationship between two persons.

This characteristic enables a graph model to represent and store the data in a comprehensive format. Both - nodes and edges - can be described with additional properties. This allows to store properties of the objects (e.g. ‘age’, ’birthday’, etc.) within the graph. It also allows to base queries (e.g. filter) on these properties. The structure of a graph also allows to traverse through the database in a logical manner. E.g. what are the names of my friend's friends?

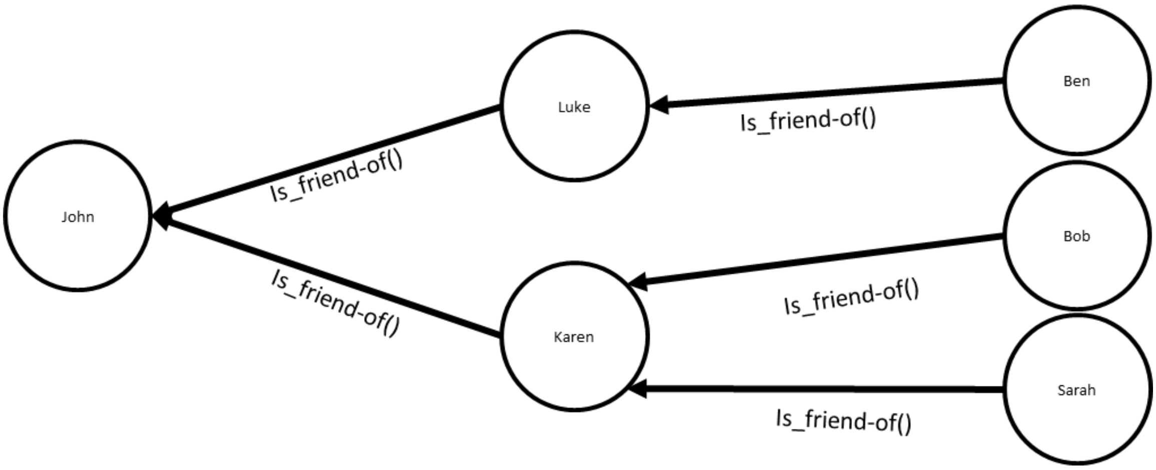


Figure 3-3: Graph example with multiple nodes and edges

This particularity allows designing, updating and analyzing the graph data base without a deeper understanding of the underlying structure or technology. Typically, a graph database also increases the speed of complex queries on large datasets. There are two main reasons we finally chose a graph database over a relational database, to model the environment of the IEA-TCPs: On the one hand, the comprehensive data structure allows interested parties to quickly understand the structure of the model and the relationships between the different entities. On the other hand the advanced visualization options allow a presentation-friendly display of the underlying data and the respective patterns.

3.2 Neo4j Graph Platform

Graph databases and models require a database framework. There are several different (open-source and commercial) solutions available on the market. The most common platform is called "Neo4J". Neo4J is implemented in Java and uses Cypher as query language. It also provides APIs (Application Programming Interface) for other programming languages (Python, JavaScript), which allow a distributed application of the models. Additionally, the framework includes a browser interface. This interface allows the visual examination of the model and its structure (this feature has proven very helpful during the development of the model). The model itself can be exported as .graphml file and be reloaded into other frameworks, which are able to interpret this file format.

In order to use (query or update) the IEA-TCP-graph model it is required to install a Neo4J or a similar frame-work. However, since the model was developed in Neo4J it is recommended using this framework. The download of a non-commercial version of Neo4J is available at their homepage[4].

3.3 Query Language Cypher

The communication with the database itself is based on a standardised query language. Commands written in this language can be interpreted by database frameworks. The query language used by Neo4J databases is

[4] https://neo4j.com/

called Cypher. Cypher is a declarative graph query language that allows for expressive and efficient querying and updating of a property graph. Cypher is a relatively simple but still very powerful language.

Cypher is based on property graph models, where nodes (entities) can have labels and properties and edges (relationships) must be of a certain type (see above). Properties are key value pairs, where the key is represented by a certain keyword (e.g. 'birthday' or 'name') and the corresponding value (05-02-1960 or "John"). The syntax of Cypher is more or less based on SQL and ASCII word art. Users, who are familiar with SQL, will find many similarities within the set of keywords and native functions. The complete and detailed documentation of Cypher can be found here[5]. In order to work with the data model in its current state a basic knowledge of the query language is required. Therefore a quick and simple introduction of the basic cypher syntax is provided at this point.

Cypher is based on the 'Property Graph Model', which in addition to the standard graph elements of nodes and edges (which are called *relationships* in Cypher) adds labels and properties as concepts. Nodes may have zero or more labels, while each relationship has exactly one relationship type. Nodes and relationships also have zero or more properties in form of a keyword and some value representing the expression of this property.

The two central concepts of Cypher are the nodes and the edges. Within the Cypher syntax this is accommodated by a special convention of formatting:

Nodes are referred to by **round** brackets. This shall resemble a circle representing a node. After the colon the type of the node is defined.

(Nodename:Nodetype)

Edges are referred to by square brackets and each left and right a minus symbol with an optional 'greater' sign. This shall resemble a labelled arrow.

-[Edgename:Edgetype]->

The nametag is always limited to a query and loses its validity outside of the query while the type is an attribute of the node or edge. Referring to Figure 3-2 the syntax fetching the relationship between two people looks something like this:

MATCH (Johnny: Person {name: 'John'})-[:knows]->(Kari :Person{name: 'Karen'}) **RETURN** ALL

MATCH is a Cypher´s specific keyword. It triggers a search process where the subsequent pattern is *matched*. MATCH is followed by the starting node of the traversal. The key-value pairs within the curly braces define the expression of the attributes of the nodes or edges. Within the variable "Johnny" all nodes with the type "Person" and the name-attribute: "John" are stored. The second part of the query (-[:knows]->) describes a unidirectional relationship of type "knows" without any additional information. The third part of the query again is a node. This node matches all nodes of the type "person" with the name-attribute "Karen" as "Kari". The RETURN keyword causes the return of the subsequently defined values. In this example the keyword "ALL" refers to all matched values, without any additional filter or information extraction. The return value is therefore a string representation of the nodes and edges. The complete query can be summarised as follows:

[5] https://neo4j.com/docs/developer-manual/current/cypher/

Match (search) all persons with the name John, who knows another person with the name Karen and return all available information of this pattern (node-relationship- node- constellation).

This basic example illustrates the comprehensiveness of queries written in Cypher. This advantage of graph based models allows more complex or longer queries. Nonetheless it is important to understand the underlying schemata of the graph model in order to formulate meaningful queries.

3.4 Used Software Versions

We used Neo4j Version 3.2.6 for the implementation of the graph database.

The visualisations were generated with Gephi Version 0.9.2.

4 Structural Analysis of the Dataset

4.1 Description of Data Structure

The design and understanding of the structure (i.e. meta-graph) of the graph model is a fundamental process. Within the neo4J browser the function *db.schema* returns the meta graph of the model, which allows a visual examination of the model. This includes all node-types and all relationships. Simultaneously it allows validating the correct representation of the underlying data.

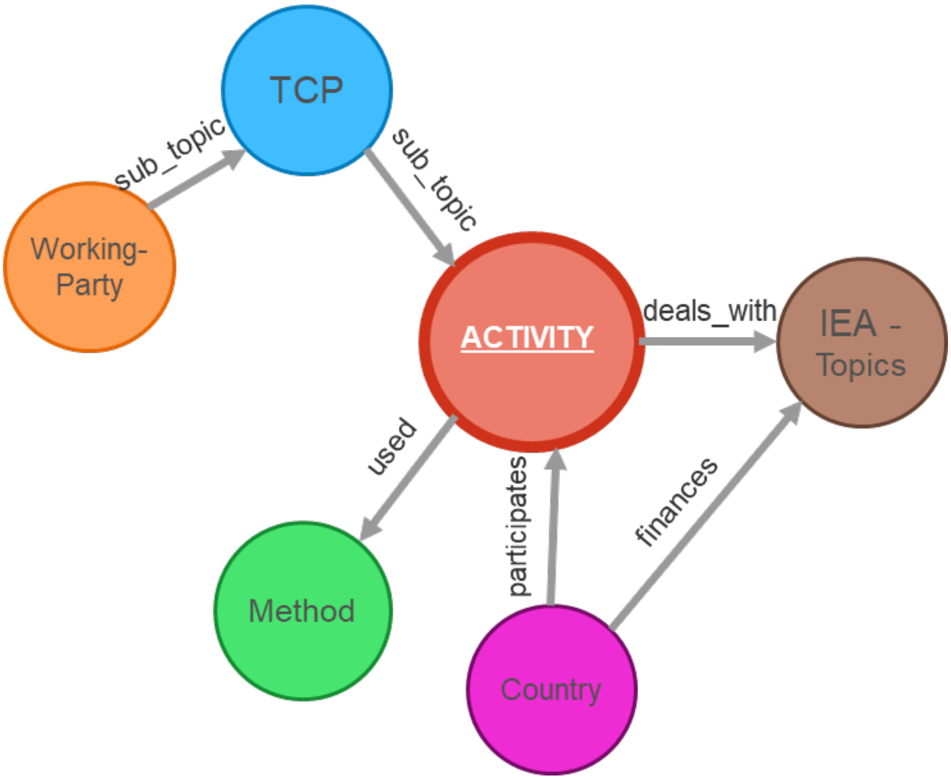


Figure 4-1: Meta-graph of the IEATCP graph database

The TCP–activities (or tasks/annexes) are the central entity of the IEATCP graph model. Activities are associated with the respective TCP. The TCPs are associated with the respective working party. This part of the model is hierarchically structured. This sub-graph resembles the structure of the organization of the IEA research efforts. Both organizational levels are implemented as nodes. The relationship type within this structure is “sub_topic”. The resulting pattern is

```
(activity)-[sub_topic]-(TCP)-[sub_topic]-(working party)
```

Every activity has participating countries[6]. These countries are represented by independent nodes. If a country participates in an activity, a relationship of the type "participates" is created. The resulting pattern is

```
(country)-[participates]-(activity).
```

The activity itself uses specific methods, based on what kind of work they are doing (see chapter 2.3). Each activity was assigned 1 to 3 methods. The methods themselves are nodes and are connected to the activity via the relationship type "used" - so that the pattern

```
(activity)-[used]-(method)
```

results. Every activity also has associated IEA-topics, based on what kind of topic they are dealing with. Each activity was assigned to up to three different IEA-topics. If an activity deals with a topic, a relation type "deals_with" is created. The resulting pattern is

```
(activity)-[deals_with]-(IEA_topic).
```

Note that the IEA taxonomy for RD&D expenditures has a 4 level hierarchical structure which goes from low detail (e.g. first level topic number 3: "Renewable Energy Sources" to high details (e.g. fourth level topic number 3.4.1.4 "Algal Biofuels") (See annex 7.3). When linking activities to IEA-topics it was tried to be as accurate as possible and link the activities to the topic number with the highest level of detail. However, in order to allow aggregated analyses of upper hierarchy levels connecting to activities, additional edges were established from each activity to all superior taxonomy levels. E.g. If activity "A" was assigned to topic 3.4.1.4, four edges are created:

```
(A)-[deals_with]-(IEA-Topic 3.4.1.4)
(A)-[deals_with]-(IEA-Topic 3.4.1)
(A)-[deals_with]-(IEA-Topic 3.4)
(A)-[deals_with]-(IEA-Topic 3).
```

An additional connection between country and IEA-topics represents the respective research budgets declared by the countries (see chapter 2.2). All country IEA-topic combinations have a relationship of the type "finances". This relationship has an attribute (budget), that resembles the associated budget.

This structure allows analysing the data with conventional descriptive statistical means, but also to create sub-sets of data based on specific research questions. This allows formulating very specific questions and leads to interesting insights of the organisation of the IEA–TCP framework. An extensive list with all node properties is given in Annex 7.4.

4.2 The Complete Graph

Linking all the above mentioned data sources into one graph data model results in a model with 499 nodes and 5,711 different relationships between these nodes. The complete dataset is available for download[7] in .graphml and .csv format, which can be imported into NEO4J (or any other graph based database system).

[6] Participating non-governmental bodies were not considered.

[7] http://documents.energyagency.at/index.php/s/1xDodz26z5BybW8

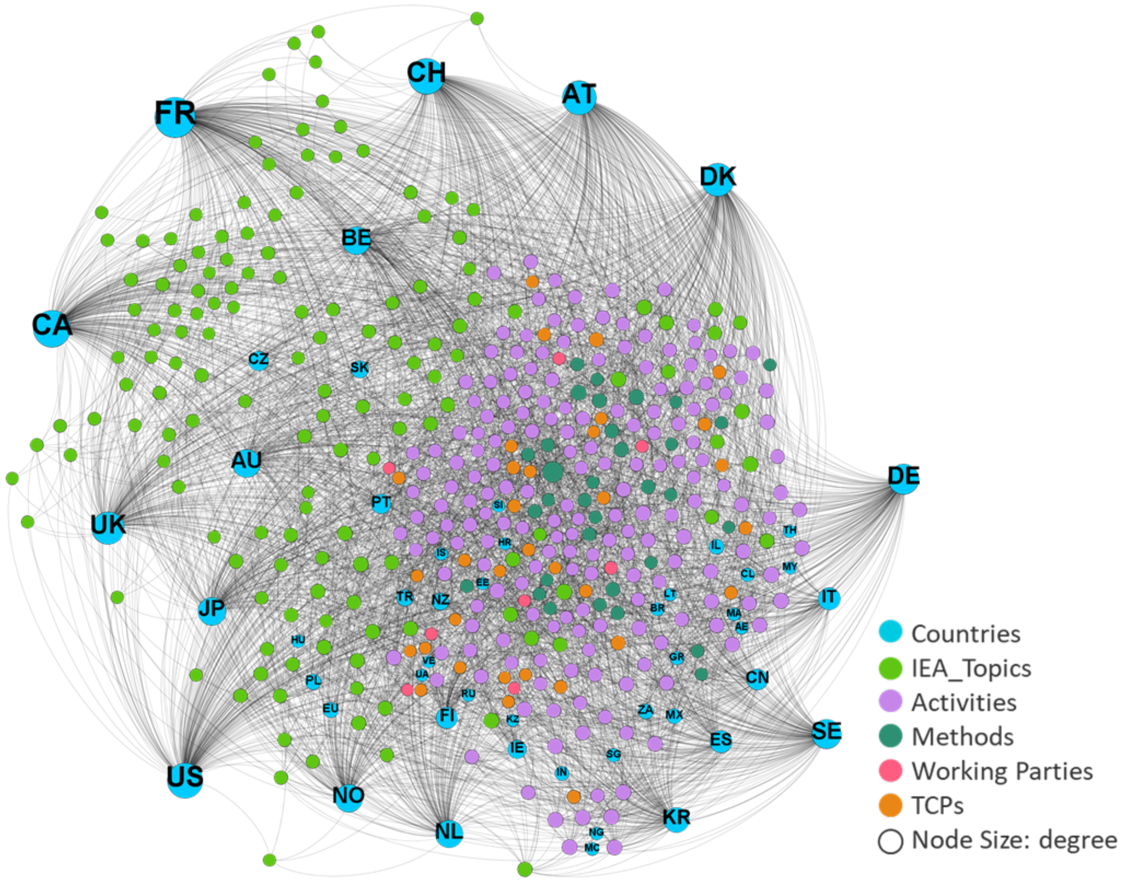


Figure 4-2: IEA TCP data graph. The node size is proportional to the level of connectedness ("degree") of the respective node.

The resulting full graph with all countries, IEA-topics, activities, methods, working parties and TCPs is shown in Figure 4-2: IEA TCP data . As you can see the whole graph is relatively complex and convoluted and it seems difficult to derive detailed insights from looking at the whole graph directly. However, what you can already see on this aggregated level is that in general, countries do have the most connections from all our node types, and some countries (or other node types) have more connections than others[8].

However, in order to answer more detailed research questions it is necessary to create smaller sub-sets of data which correspond to the question asked. With the Neo4Js query language "Cypher" we have a mighty tool at hand, which allows us to do just that. If desired, the output can also be given in form of a table, which allows for easier processing in spreadsheets. The following sections aim to give an overview of the dataset by answering some basic questions.

[8] The level of connectedness is called "degree" in graph science and is shown as node size in the figure above.

4.3 Combination of Methods

Figure 4-3 shows which methods are applied how often in total (node size), and which methods were frequently applied together (edge width) by activities. The color corresponds to the different method categories described in chapter 2.3 (Figure 4-4 shows the same information for the top 7 most counted methods in matrix format).

The graph shows that ARES ("Applied Research") has by far the most nominations, and activities that deal with ARES frequently also deal with POLE ("Policies and legislation"), TEST("pre-standardisation, testing protocols and product testing") and BEST ("Best Practice"). On the other hand no TCP-activity was assigned to the field of DATA ("Big data, protection of data privacy") and EMSA ("Energy management systems and audits").

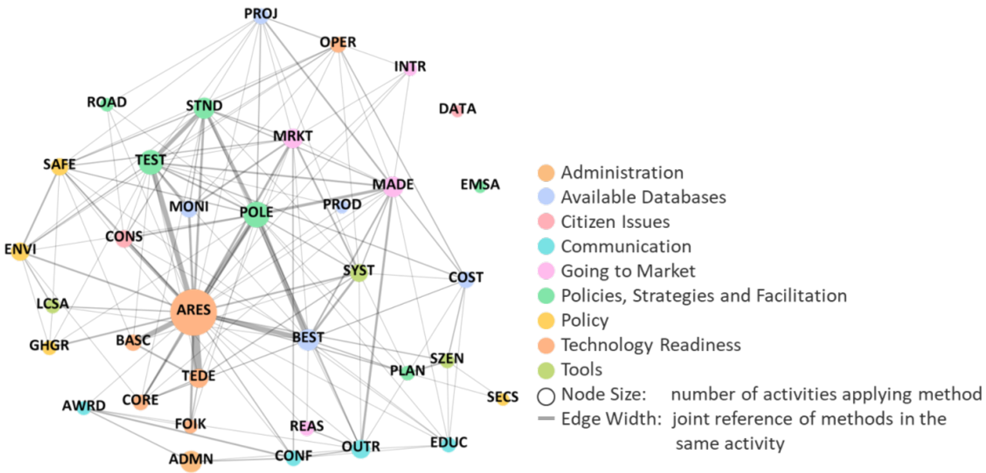


Figure 4-3: Combination of methods used by TCP-activities (graph form)

	ARES	POLE	TEST	BEST	STND	MADE	MRKT
ARES		8	9	8	4	1	4
POLE	8		3	9	6	5	1
TEST	9	3		1	7	3	1
BEST	8	9	1		0	3	1
STND	4	6	7	0		2	2
MADE	1	5	3	3	2		1
MRKT	4	1	1	1	2	1	0

Figure 4-4: Combination of methods used by TCP-activities (only the seven most mentioned methods, matrix format)

4.4 Worldwide Cooperation

The described methodology allows evaluating how often countries are working together in TCP-activities.

Fehler! Verweisquelle konnte nicht gefunden werden. shows a world map, each IEA member (or cooperating c ountry) is marked as a node. The size of the node corresponds to the total size of the RD&D budget 2015. The color of the node corresponds to the number of activities the country is participating in (darker = more activities). The thickness and color of the edges between countries corresponds to the number of activities that both countries are participating together.

The graph shows no unexpected results: Cooperation between IEA member states focuses on European countries. Outside Europe we find fewer, but relevant, countries participating in TCP-activities.

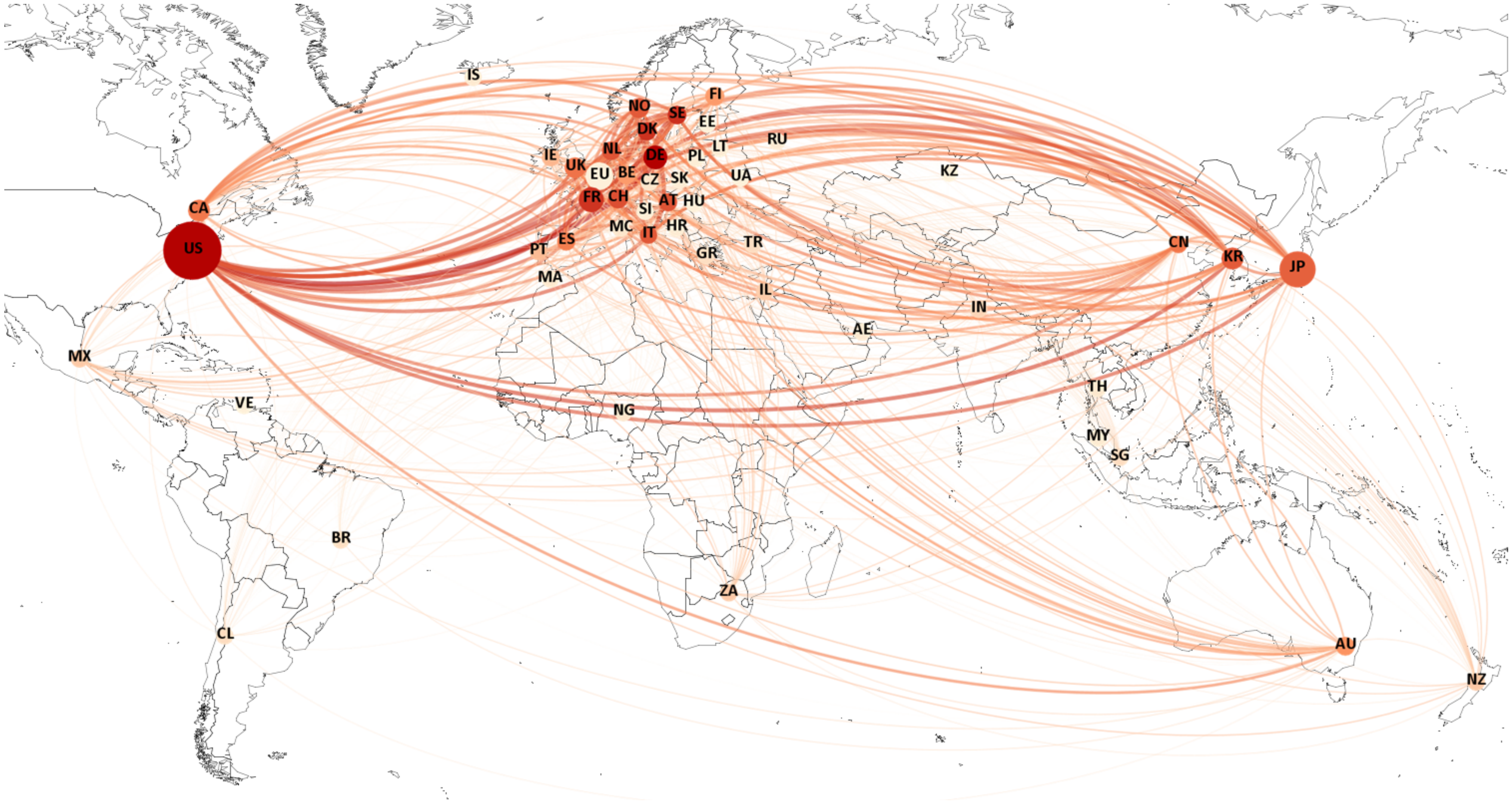


Figure 4-5: Worldwide cooperation of countries in TCP-tasks/annexes. Node size: Total RD&D budget 2015. Node colour: Number of participated activities. Edge width: activity-cooperations between countries.

4.5 Countries: Participation in TCPs and Related Research Topics

Figure 4-6 shows the absolute (upper chart) and relative (lower chart) number of TCP-activities that countries are participating in. The color code shows how the assigned activities are related to the IEA-Topics. Note that double countings occur for activities that are assigned to more than one IEA-Topic[9].

The color code allows to get a quick picture which kind of activities the countries are assigned to, and how they set their priorities with regard to the research topics (based on the IEA RD&D taxonomy).

In the upper part of the figure we can see that there are about 16 very active countries that participated in more than 60 activities. As you can see, most activities are related to IEA-topic 1 (Energy Efficiency) and 3 (Renewable Energy Sources). The lower part of the figure shows how countries set their priorities with regard to the IEA-topics[10]. We can see that e.g. Austria has a strong focus on energy efficiency, with roughly 40% of its TCP-activities being associated to IEA-topic 1[11].

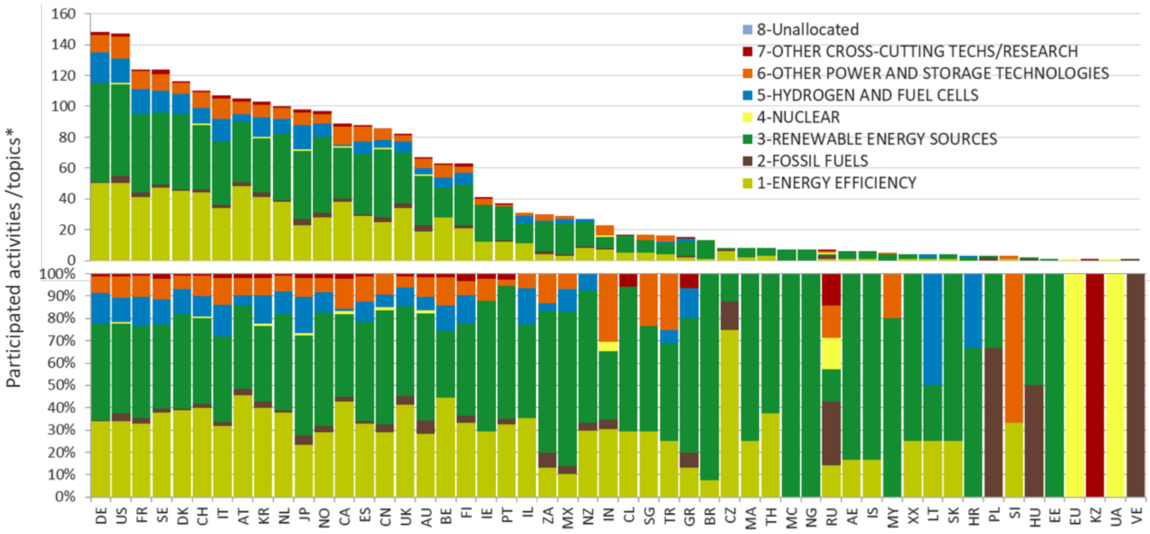


Figure 4-6: Absolute (top) and relative (bottom) number of participated activities per country. The color corresponds to the IEA-topic the participated activities are associated with. Activities that are assigned to more than one TCP-topic are counted multiple times.

Figure 4-7 shows similar information, but ordered by IEA-topic. Each "country activity" (given on the Y-Axis) constitutes one country participating in one activity[12]. This chart shows well, that most activities in IEA-topic 1 ("Energy Efficiency") are related to EUWP-activities. However, there is also an intersection of activities that are dealing with topic 1, but are assigned to REWP-activities. Also the topic "Other Power and Storage Technologies" is mostly populated by EUWP-activities. The topic "Hydrogen and Fuel Cells" is populated equally by both, EUWP and REWP-activities. Note that IEA-topic 4 ("Nuclear") is out of scope of this paper and is displayed only for the sake of completeness of the IEA-taxonomy.

---

[9] E.g. an activity that is assigned to IEA-topic 1 "Energy efficieny" and 3"Renwable energy" will be counted and displayed in both categories. This leads to a slight deviation of activities counted compared to simply counting the absolute number of activities per country.

[10] Implicitly it is assumed that all activities are weighted equally. This is of course an oversimplification, as some TCP-activities are more active than others.

[11] When the number of participated activities sinks below about 60 the relative distribution of IEA-topics becomes statistically less significant, resulting in a "noisy" picture in the lower-right part of **Fehler! Verweisquelle konnte nicht gefunden werden.**.

[12] As in the figure above, double countings occur if one activity is associated to more than one IEA-topic.

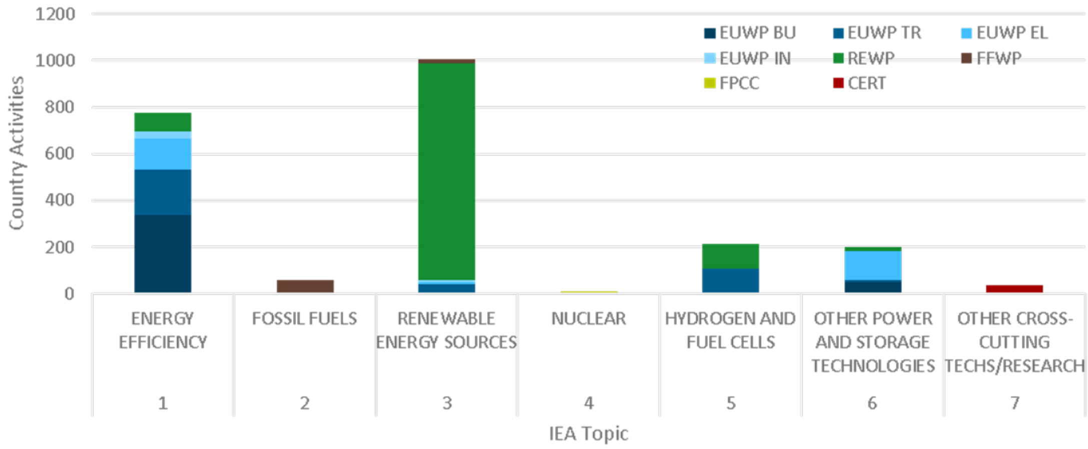


Figure 4-7: Country-Activities per topic and involved working parties

4.6 IEA-Topics, Related Activities and Working Parties

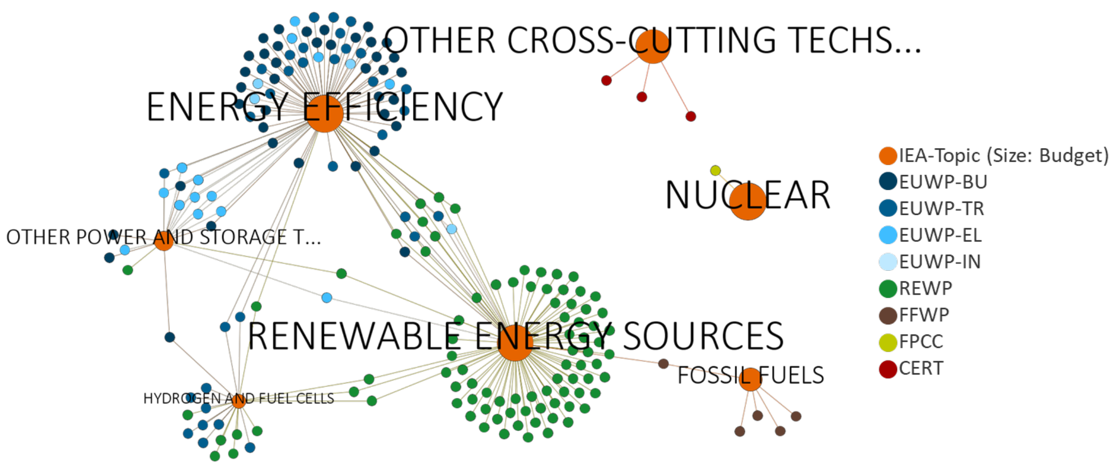


Figure 4-8: Graph: IEA-topics on level 1 (orange, node size corresponds to the official RD&D budget 2015) and TCP-activities (non-orange nodes) and related TCP-working parties (see color code in legend).

Figure 4-8 shows how IEA-topics and TCP-activities are interrelated in form of a graph. Orange nodes represent the seven main IEA-topics (node size corresponds to the official RD&D budget 2015), non-orange nodes represent TCP-activities.

As we can see, the topics “Energy Efficiency” and “Renewable Energy Sources” have a relatively big budget, and also a relatively large number of associated activities. On the contrary “Other cross-cutting technologies” and “Fossil Fuels” are also relatively important with regard to their RD&D budget, but they have much less associated activities[13]. The topic “Hydrogen and Fuel Cells” has relatively many activities with regard to the size of their RD&D budget.

[13] As stated already earlier, nuclear TCPs and topics were excluded from detailed analysis, and hence there are fewer activities displayed than actually exist.

In general the graph shows that there are many activities that are only associated to one thematic topic. However, activities that are connected to more than one IEA-topic constitute the thematic intersection between different research fields. E.g. IEA-topic 6 "Other Power and Storage Technologies" and IEA-topic "Renewable Energy Sources" are connected via two activities[14]: "High Temperature Superconductivity" (HTS, EUWP) and "High penetration of PV System in Electricity Grids" (PVPS, REWP). They are of special interest in order to avoid overlaps (especially if they belong to different working parties, where the flow of information might be limited).

4.7 Main Sub-Topics in EUWP Coordination Groups

Each TCP-activity of EUWP TCPs is assigned to 1 - 3 IEA-subtopics (see chapter 2.2). Figure 4-9 shows the five subtopics that activities most often refer to. Additionally the color allows to see to which coordination group the allocations belong to.

As you can see the four most popular topics in EUWP are all building related. The fifth most popular topic is fuel for on-road vehicles.

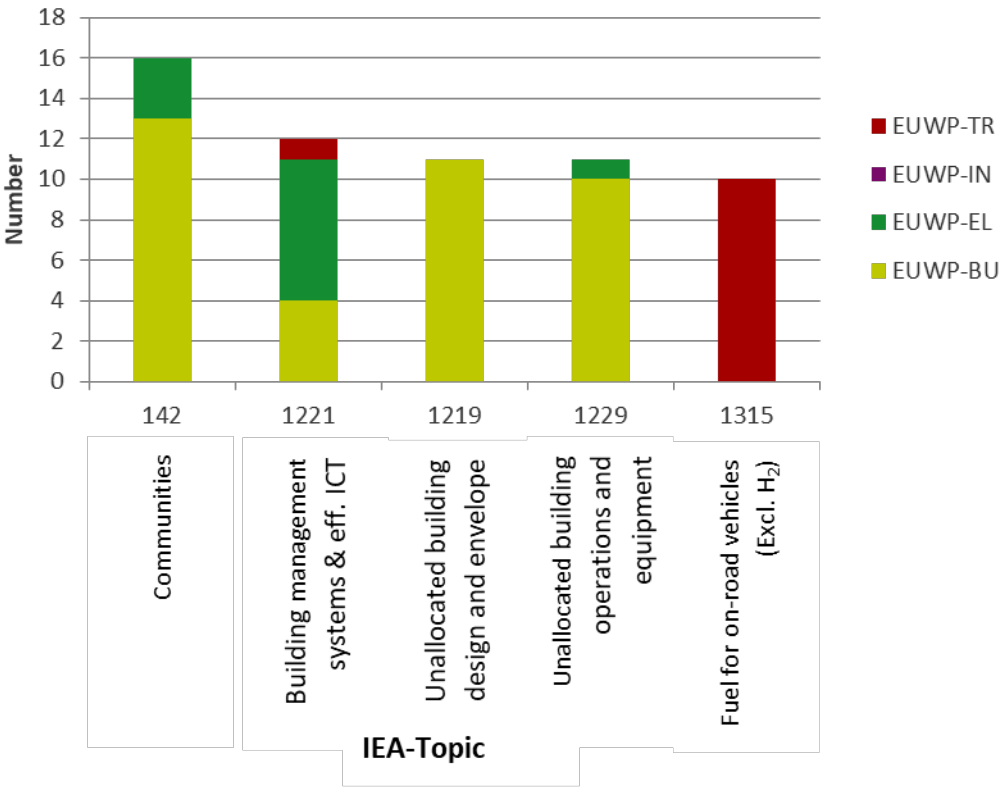


Figure 4-9: Main IEA-sub-topics that are handled in EUWP-activities

[14] Activity names are not displayed in the graph but only represented as nodes.

5 Selected Analysis for Reproduction

As already stated above, the full graph (Figure 4-2) carries too much information to be very useful in answering specific research questions. Instead it is necessary to "zoom into" the graph by filtering the full dataset according to the desired question and with regard to the given data pattern. Once NEO4J is in place and the data is imported, the user can start writing his own queries to answer specific research questions.

The following section aims to provide some guidance on which kind of questions can be asked, and how they can be answered using Neo4J and Cypher as basic tools. Please note that it is not possible to give guidance on every possible utilisation of this dataset, as the specific use depends on the users' preferences and interests. However, altering the given Cypher queries slightly (e.g. by changing the name of the TCP) can serve as a starting point for more refined analyses.

5.1 Example Queries – Topics

Observation: There seem to be a lot of hydrogen related activities in TCPs, yet the RD&D budget for the IEA-topic 5 "Hydrogen and fuel cells" is relatively small.

Question: In which working parties and TCPs can we find activities that are allocated to the IEA-topic "5.1 Hydrogen"? In which TCPs is Austria participating?

Cypher Query:

```
MATCH (top:IEA_Topic{Number:51})--(act:ACT)--(tcp:TCP)--(wp:working_party)
return top.Name,wp.Name, Count(act),tcp.Name, Exists((tcp)--(act)--
(:Country{ISO:"AT"}))
```

Answer: Figure 5-1 shows a screenshot of the list resulting from the above cypher query. As we can see REWP two coordination groups of EUWP (TR and BU) are involved. The most related activities can be found in the TCP "Hydrogen" (REWP), but there are also 6 other activities in 4 more TCPs dealing with the topic "Hydrogen". Austria is involved in hydrogen issues via 2 of 3 related "fuel-cell-activities".

$ MATCH (top:IEA_Topic{Number:51})--(act:ACT)--(tcp:TCP)--(wp:working_party) return top.Name,wp.Name, Count(act),tcp.Name, Ex…

top.Name	wp.Name	Count(act)	tcp.Name	Exists((tcp)--(act)--(:Country{ISO:"AT"}))
"Hydrogen"	"EUWP TR"	1	"Energy Conservation and emissions reduction in combustion"	false
"Hydrogen"	"EUWP TR"	1	"Advanced Fuel Cells"	false
"Hydrogen"	"EUWP BU"	1	"Energy Conservation through Energy Storage"	false
"Hydrogen"	"REWP"	9	"Hydrogen"	false
"Hydrogen"	"REWP"	1	"Concentrated Solar Power"	false
"Hydrogen"	"EUWP TR"	2	"Advanced Fuel Cells"	true

Figure 5-1: In which working parties and TCPs can we find activities that are allocated to the IEA-topic „5.1 Hydrogen"? In which is Austria participating?

A slight modification of the query code yields graphical results:

```
MATCH (top:IEA_Topic{Number:51})--(act:ACT)--(tcp:TCP)--(wp:working_party)
return top,wp,act,tcp
```

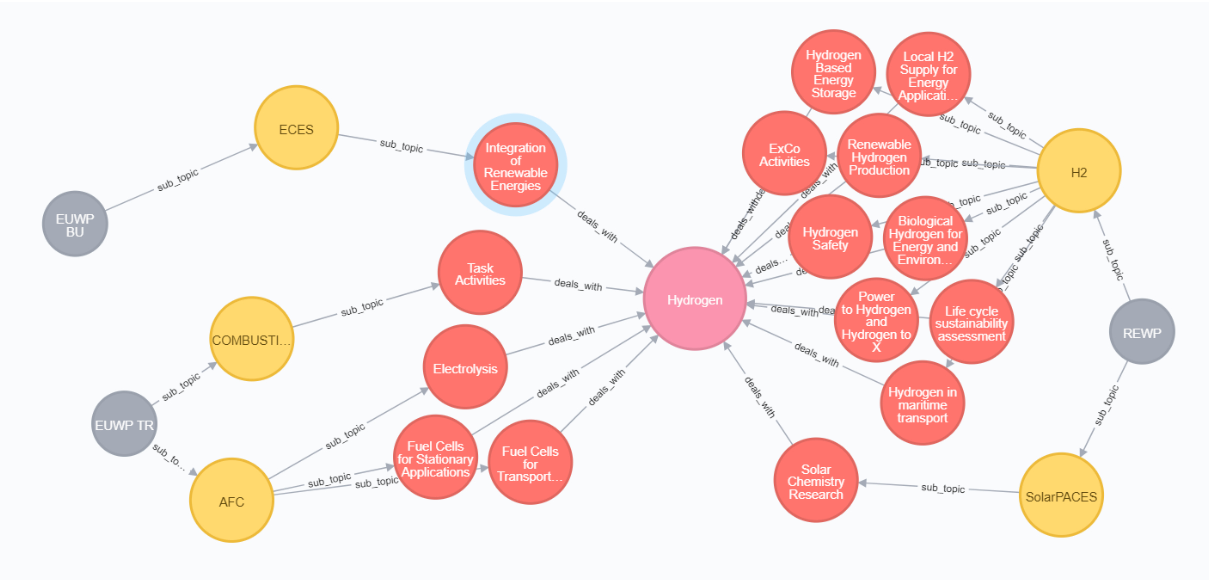


Figure 5-2: In which working parties and TCPs can we find activities that are allocated to the IEA-topic “5.1 Hydrogen”?

5.2 Example Queries – Working Parties

Question: Which activities within the EUWP are working in the field of policy and legislation (method POLE, ROAD and STND)?

Cypher Query:

```
match (a:ACT)--(b:METH)
where b.Abbrev IN ["POLE", "ROAD", "STND"] AND a.WP IN ["EUWP IN", "EUWP BU",
"EUWP EL", "EUWP TR"]
return a,b
```

Answer: Figure 5-3 shows which EUWP-activities are using the defined methods, and how they are interrelated.

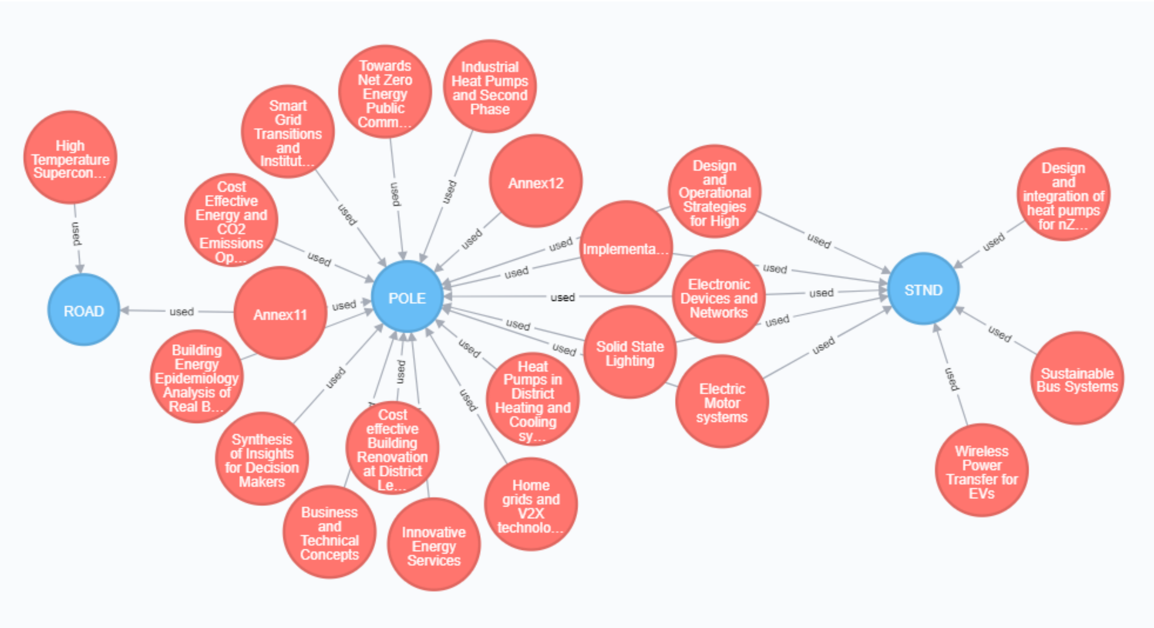


Figure 5-3: Which activities within the EUWP are working in the field of policy and legislation?

If the output as a list is preferred, the following query can be used, yielding the table given in Figure 5-4.

Cypher Query:

```
match (a:ACT)--(b:METH)
where b.Abbrev IN ["POLE", "ROAD", "STND"] AND a.WP IN ["EUWP IN", "EUWP BU",
"EUWP EL", "EUWP TR"]
return a.Name, a.TCP, count (b)
```

a.Name	a.TCP	count (b)
"Synthesis of Insights for Decision Makers"	"ISGAN"	1
"Annex12"	"DHC"	1
"Business and Technical Concepts for Deep Energy Retrofit of Public Buildings"	"EBC"	1
"Design and integration of heat pumps for nZEB"	"HPT"	1
"High Temperature Superconductivity"	"HTS"	1
"Home grids and V2X technologies"	"HEV"	1
"Electronic Devices and Networks "	"4E"	2
"Wireless Power Transfer for EVs"	"HEV"	1
"Annex11"	"DHC"	2
"Innovative Energy Services"	"DSM"	1
"Industrial Heat Pumps and Second Phase"	"HPT"	1
"Design and Operational Strategies for High IAQ in Low Energy Buildings"	"EBC"	2
"Towards Net Zero Energy Public Communities"	"EBC"	1
"Solid State Lighting"	"4E"	2
"Sustainable Bus Systems"	"AMF"	1
"Cost effective Building Renovation at District Level Combining Energy Efficiency and Renewables"	"EBC"	1
"Electric Motor systems"	"4E"	2
"Heat Pumps in District Heating and Cooling systems"	"HPT"	1
"Implementation of Energy Strategies in Communities"	"EBC"	2
"Cost Effective Energy and CO2 Emissions Optimization in Building Renovation"	"EBC"	1
"Building Energy Epidemiology Analysis of Real Building Energy Use at Scale"	"EBC"	1
"Smart Grid Transitions and Institutional Change"	"ISGAN"	1

Figure 5-4: Which activities within the EUWP are working in the field of policy and legislation (table output)?

5.3 Example Queries - TCPs

5.3.1 Energy in Buildings and Communities EBC

Question: Which activities are subsumed in the EBC-TCP, which methods do they use, which methods are used most frequently and which activities apply the same methods?

Cypher Query: `match n=(:ACT {TCP:"EBC"})--(:METH) return n`

Answer: EBC has 18 activities (including ExCo activities), the most commonly used methods are “ARES” and “POLE”. Which activities apply the same methods can be seen from the graph.

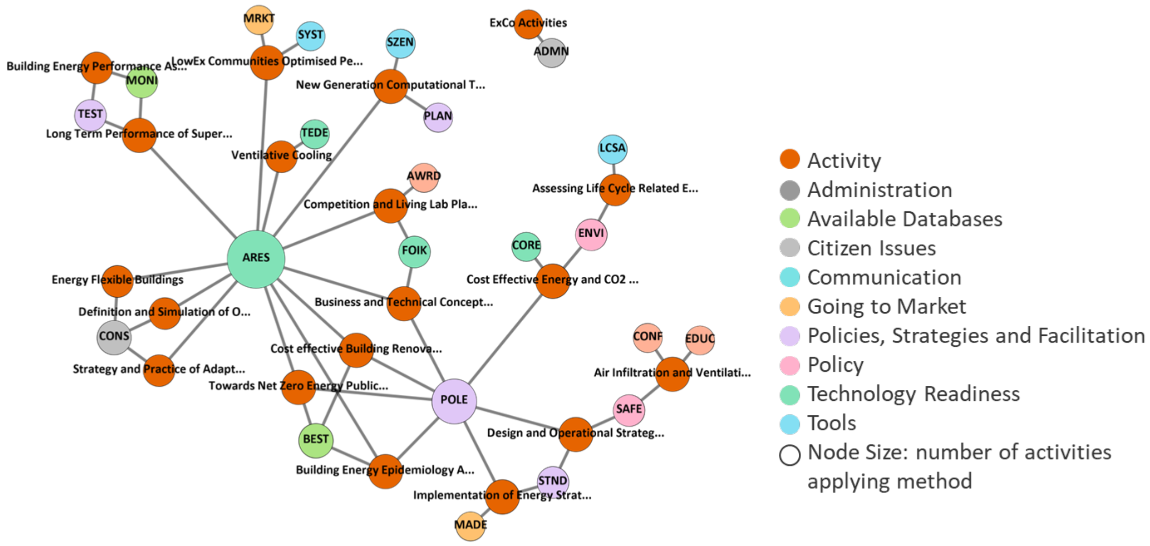


Figure 5-5: Energy in Buildings and Communities (EBC) – activities (orange) and methods (node size: number of activities applying method) by method group (colour). Legend and colour coding by AEA

5.3.2 Advanced Motor Fuels AMF

Question: Which other TCPs are active in the same “fuel topics” (IEA-topics 1315, 132, 3419) as AMF?

Cypher Query: `match (act:ACT {TCP:"AMF"})--(topic:IEA_Topic)--(act2:ACT)--(tcp:TCP) where topic.Number IN [1315,132,3419] return act,topic,act2,tcp`

Answer: Other than AMF the TCPs “HEV”, “COMBUSTION” (both EUWP), “BIO” and “H2” (both REWP) are working on the defined “fuel topics”.

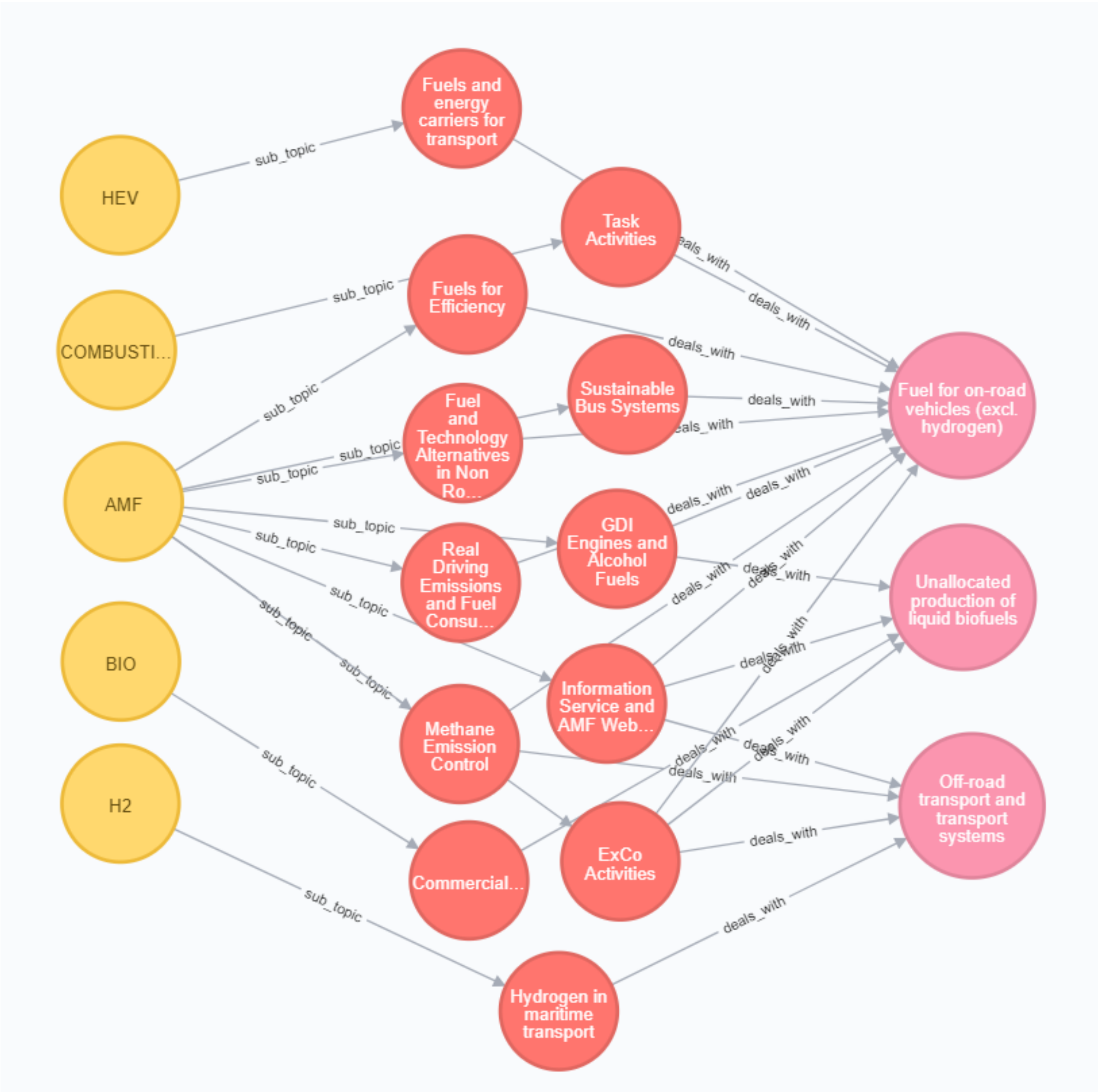


Figure 5-6: AMF - Which other TCPs are working on the same "fuel topics" as AMF?

Question: Which methods are AMF activities applying?

Cypher Query: `match n=(:ACT {TCP:"AMF"})--(:METH) return n`

Answer: The eight activities related to AMF (Red nodes) are applying methods ARES (4), TEST (4), ENVI (2), GHGR (1), STND (1), OUTR (1) and ADMN (1).

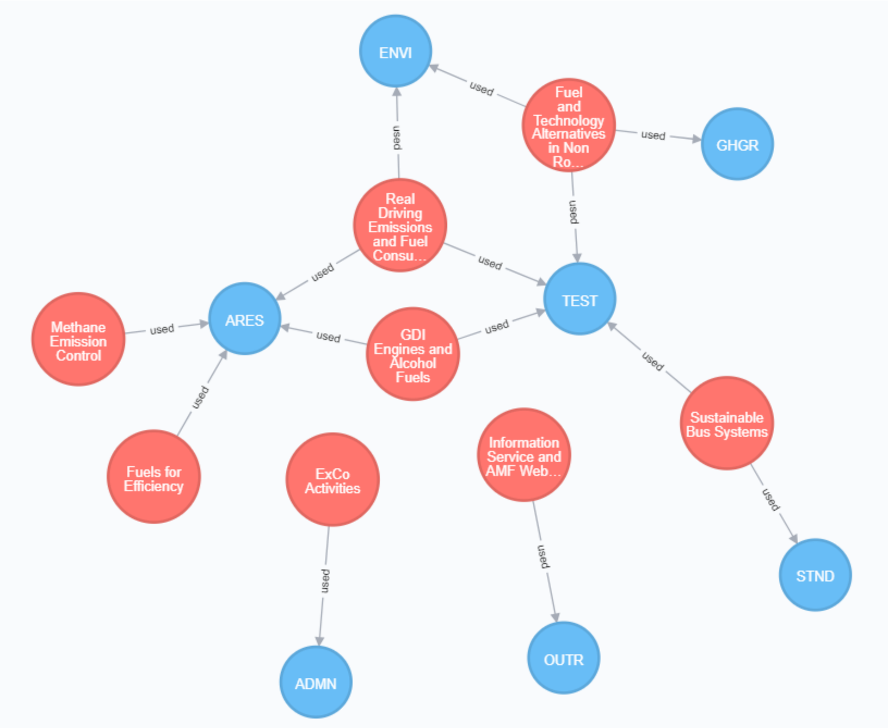


Figure 5-7: Which methods are AMF activities applying?

5.3.3 Analysis of ISGAN

Question: What are the topics „ISGAN“ deals with?

Cypher Query:
```
MATCH (tcp:TCP{Abbrev:"ISGAN"})--(activities:ACT)--(topics:IEA_Topic
{last:"True"}) return tcp, activities, topics
```

Answer: ISGAN has eight activities that are all connected to IEA-topic 629 "Unallocated electricity transmission/distribution" and 1221 "Building management systems and eff. ICT".

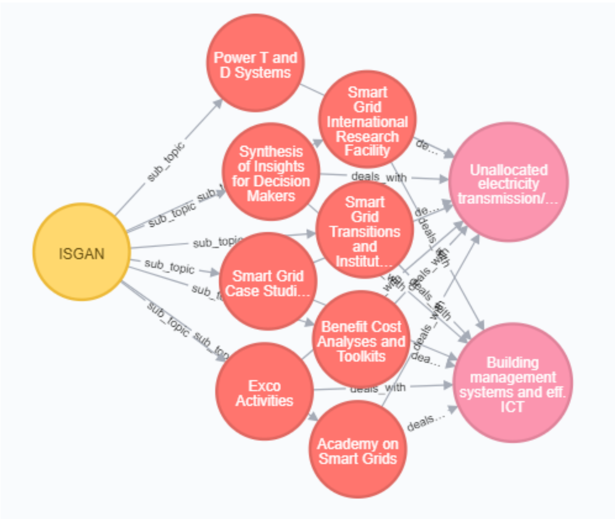


Figure 5-8: What are the topics „ISGAN“ deals with?

Question: Which other TCPs are working on the same topics as ISGAN??

Cypher Query:

```
MATCH (tcp:TCP{Abbrev:"ISGAN"})--(activities:ACT)--
(topics:IEA_Topic{last:"True"})--(other_activities:ACT)--(other_tcps:TCP)
RETURN tcp, activities, topics, other_activities, other_tcps
```

Answer: There are four other TCPs that are working on the same topic as ISGAN: Energy in Buildings and Communities, Heat Pump Technologies, Hybrid and Electric Vehicles, Energy Conservation through Energy Storage.

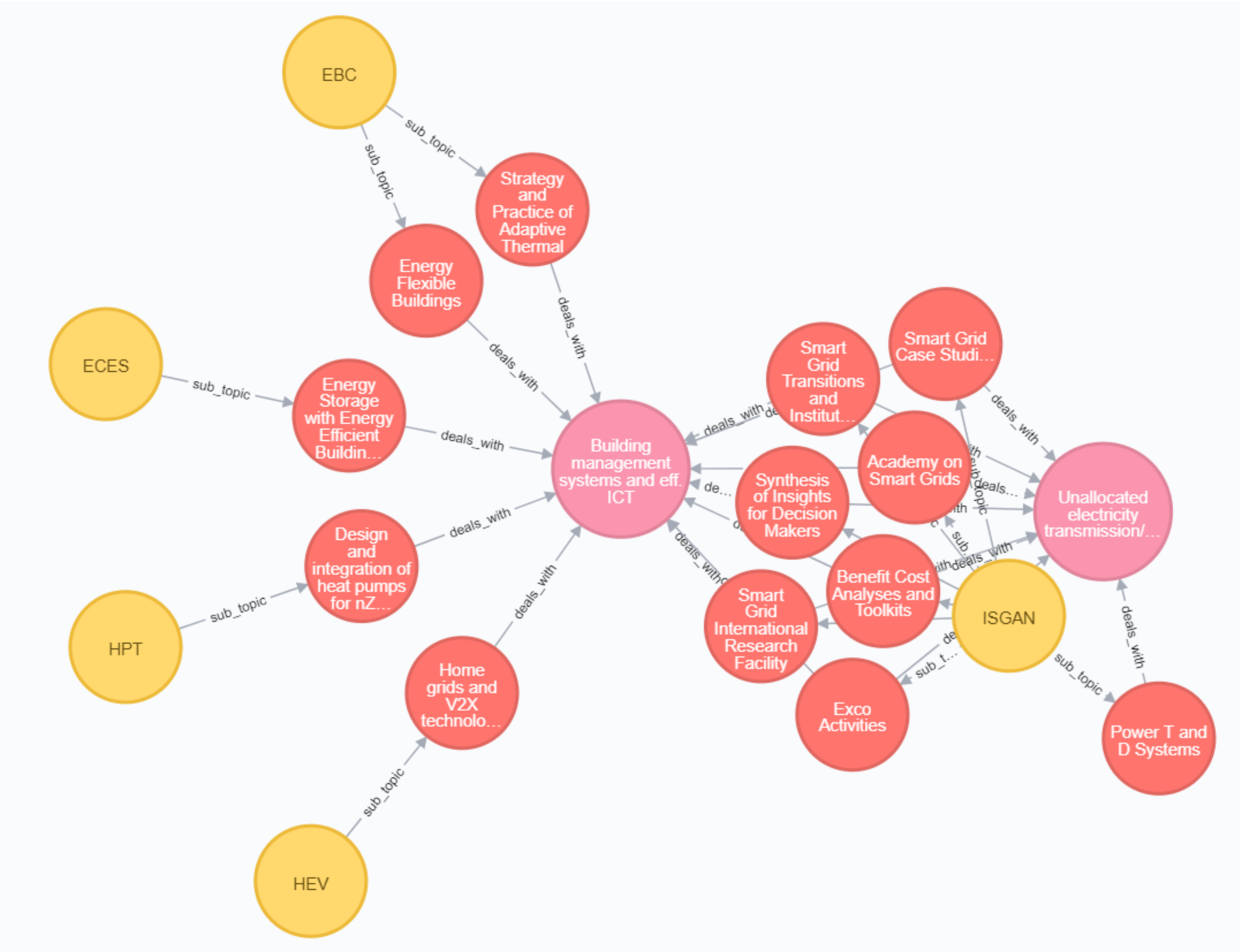


Figure 5-9: Which other TCPs are working on the same topics as ISGAN?

Question: Which methods are used by ISGAN?

Cypher Query: `MATCH (tcp:TCP{Abbrev:"ISGAN"})--(activities:ACT)--(method:METH) return method,activities,tcp`

Answer: The graph shows which methods are used by which activity. Interestingly there is only one method that is used by multiple activities (POLE), all others are used only once.

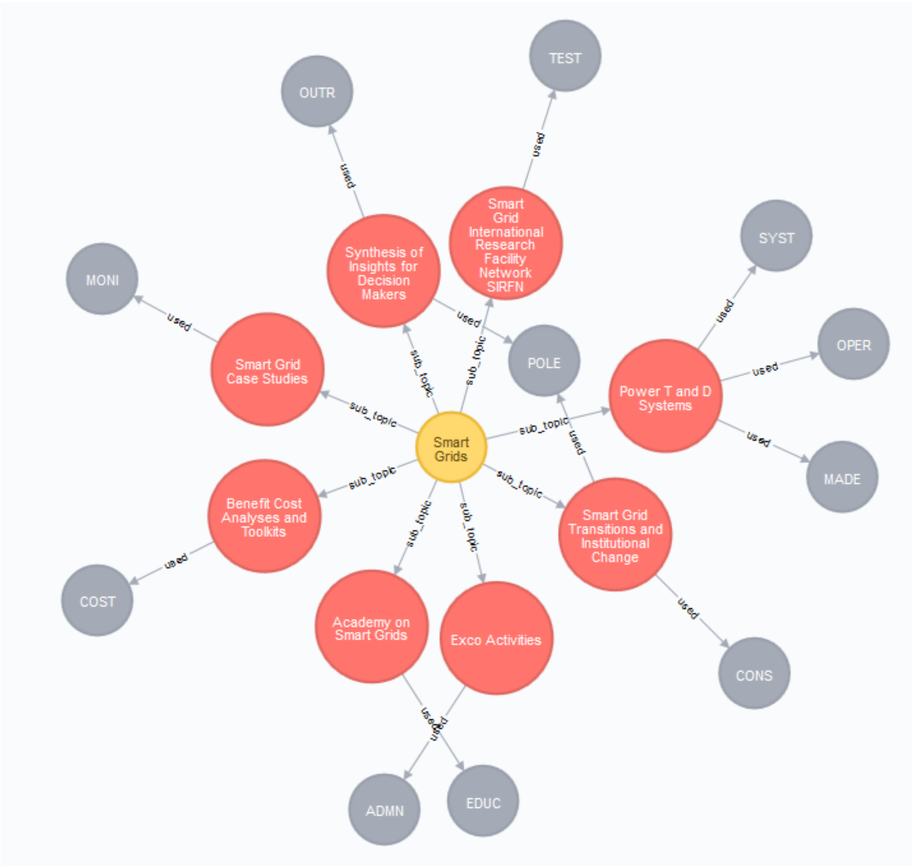


Figure 5-10: Which methods are used by ISGAN?

6 Findings and Recommendations

The following key findings and recommendations were presented and discussed at the meeting of the IEA End-Use Working Party on March 21, 2018.

6.1 Methods

The introduction of 35 methods (see chapter 2.3) to classify the activities brought some new insights, built on quantitative analysis:

- The general focus of activities was clearly on applied research (72 activities). Technological development (15 activities) and energy related basic research (9 activities) are lagging behind. Basic research might be sufficiently covered in "classical" cooperation between university researchers. The "close to market development"-activities require special protection for intellectual property rights and are always sensitive for companies to share.
- Activities in TCPs provide strong support for policies and legislations (29 activities), but also testing (26 activities) and standardisation (19 activities). Policy and technical support are clearly a strength and an added value of international cooperation.
- Data, if presented publicly, is focusing on good/best practice (20 activities).
- TCPs are very active when it comes to bringing technologies to the market and deploy them. There was a broad sample of activities with a focus on market development and deployment (18 activities) and market analysis (16 activities).
- There was substantial work on consumer behaviour and behavioural change (analysing and influencing the consumer, 11 activities), but no focus on the consumer as the subject (prosumer, privacy issues). No single activity had "big data" and protection of data privacy as an important part of digitalisation as one of their three main areas of action in 2017.

One interesting aspect to look at was the coverage of "energy policy" with the TCP-activities. A typical set of national energy policy goals is shown in Figure 6-1. Looking at the number of activities with a dedicated focus provided a clear ranking shown in Table 6-1.

Table 6-1: Aspects of energy policy in TCPs work (Source: Austrian Energy Agency)

Priority	Method (number of activities)
top	environmental aspects in general (13) and GHG reduction (5)
quite important	safety and health issues (11)
medium level	activities dedicated clearly towards cost reduction (7)
very low	security of supply as a dedicated issue of work (1)

For further interpretation it has to be taken into account that TCPs are intentionally a network for technology collaboration. Security of supply is a systemic issue, difficult to cover in sectoral activities. Quite remarkable is the substantial focus on safety and health issues.

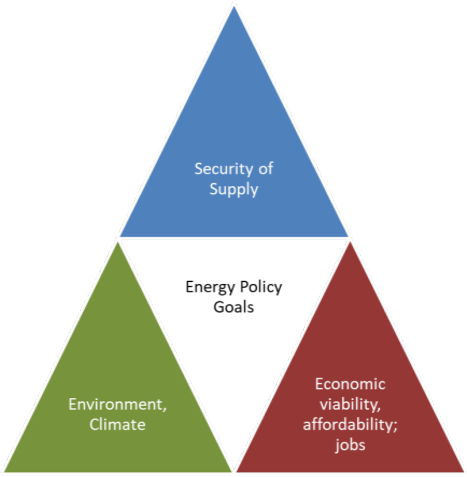


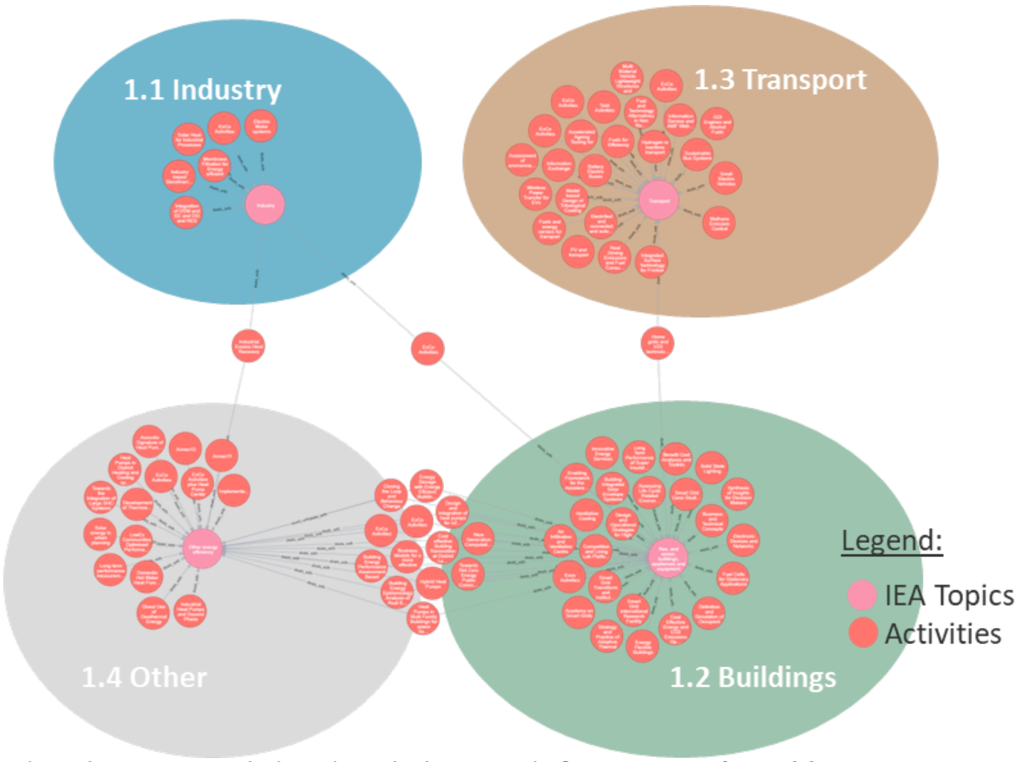
Figure 6-1: A typical set of energy policy goals (Source: Austrian Energy Agency)

6.2 End-Use Sector

The End Use Working Party with its sectoral sub-structure was the ideal setting to discuss the following observations derived from the analysis summarized in Figure 6-2:

> There is obviously a comparably low number of only six activities in energy efficiency in industry when compared to industry's share in energy consumption in end-use sectors (see Figure 6-3) and industry's important role in RD&D budget allocations (see Figure 2-2 in chapter 2).

This observation was verified by other delegates, too.




```
match (topic:IEA_Topic)--(activity:ACT) where a.Number=11 or
topic.Number=12 or topic.Number=13 or topic.Number=14 return topic,
activity
```

Figure 6-2: TCP-activities in the end-use sectors according to IEA-classification (Source: Austrian Energy Agency)

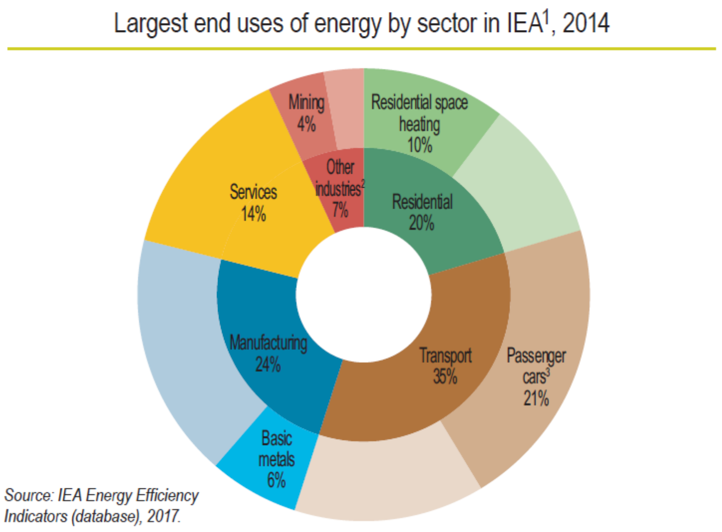


Figure 6-3: Energy end -use (Source: IEA Key World Energy Statistics, 2017)

6.3 Structure

Making full advantage of the graph-based data structure, Figure 6-4 shows to which IEA-topics all the activities are related to. The colors indicate the working parties, with End-Use Coordination Groups in different shades of blue. The size of the seven main IEA-topics is scaled with overall RD&D budget.

Internationally relevant topics like biofuels, hydrogen, smart grids, smart cities etc. are well represented (number of resp. activities). But these activities are – because often allocated in more than one TCP as shown in chapter 5 – located under various Working Parties and their Coordination Groups. So the question was raised at the meeting if the TCP network has appropriate communication structures in and between TCPs and working parties to make best use of TCPs' results and public money countries are investing in them.

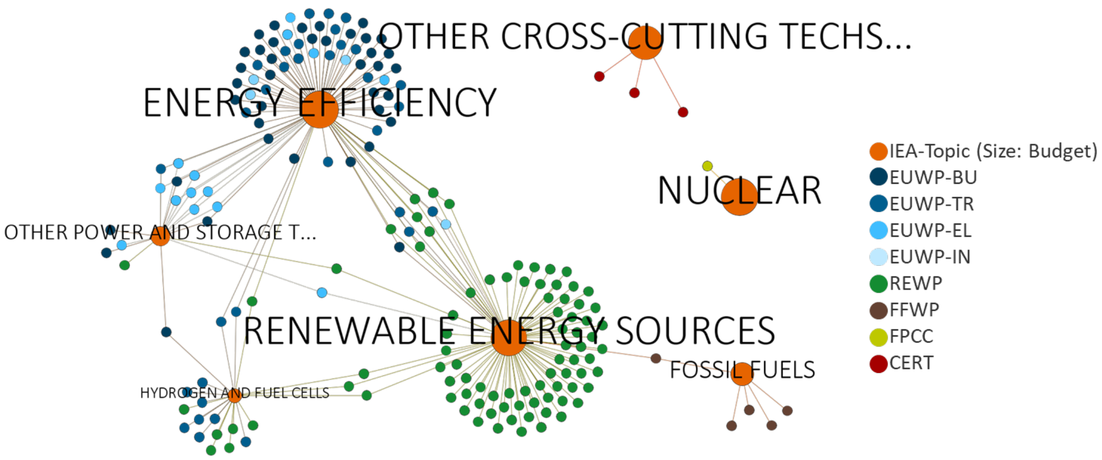


Figure 6-4: Activities related to IEA-topics (scaled by all countries' RD&D budget) and working parties (see colour) (Source: Austrian Energy Agency)

7 Annexes

7.1 List of TCPs and Activities

Activity	TCP
Solar Energy in Urban Planning	SHC
Solar Heat and Energy in Urban Environments	SHC
New Generation Solar Heating and Cooling	SHC
Price Reduction of Solar Thermal Systems	SHC
Towards the Integration of Large SHC Systems into DHC Networks	SHC
Building Integrated Solar Envelope Systems for HVAC and Lighting	SHC
Solar Standards and Certification	SHC
ExCo Activities	SHC
Material and Component Development for Thermal Energy Storage	SHC
Small Scale Hydro	HYDRO
Valuing Hydropower Services	HYDRO
Managing the Carbon Balance in Freshwater Reservoirs	HYDRO
Hydropower and Fish	HYDRO
Management Models for Hydropower Cascade Reservoirs	HYDRO
Maintenance Works and Decision Making for Hydro Facilities	HYDRO
ExCo Activities	HYDRO
ExCo Activities	H2
Hydrogen Based Energy Storage	H2
Local H2 Supply for Energy Applications	H2
Biological Hydrogen for Energy and Environment	H2
Renewable Hydrogen Production	H2
Life Cycle Sustainability Assessment	H2
Hydrogen Safety	H2
Power to Hydrogen and Hydrogen to X	H2
Hydrogen in Maritime Transport	H2
ExCo Activities	PVPS
Strategic PV Analysis and Outreach	PVPS
Deploying PV Services in Emerging and Developing Countries	PVPS
PV Environmental and Health and Safety Activities	PVPS
Performance and Reliability of PV Systems	PVPS
High Penetration of PV Systems in Electricity Grids	PVPS

Activity	TCP
Enabling Framework for the Acceleration of BIPV	PVPS
Solar Resources	PVPS
PV and Transport	PVPS
ExCo Activities	GT
Deep Roots of Volcanic Geothermal Systems	GT
Direct Use of Geothermal Energy	GT
Environmental Impacts of Geothermal Energy Development	GT
Data Collection and Information	GT
Emerging Geothermal Technologies	GT
Fusion Power	FUSION
Greenhouse Gas R and D	GHG
Clean Coal Centre	CCC
ExCo Activities	OES
Review and Exchange and Dissemination of Information on OE Systems	OES
Assessment of Environmental Effects and Monitoring Efforts for Ocean Energy	OES
Worldwide Web GIS Database for Ocean Energy	OES
Cost of Energy for OE Technologies	OES
Consenting Processes for Ocean Energy in OES Member Countries	OES
Wave Energy Modelling Verification and Validation	OES
Investigation and Evaluation of OTEC Resource	OES
International Ocean Energy Technology Roadmap	OES
ExCo Activities	WIND
Base Technology Information Exchange	WIND
Wind Energy in Cold Climates	WIND
Power Systems with Large Amounts of Wind Power	WIND
Cost of Wind Energy	WIND
Small Wind Turbines in Turbulent Sites	WIND
Social Acceptence of WInd Energy Projects	WIND
MexNet Aerodynamics	WIND
Computer Codes and Models for Offshore Wind Energy	WIND
WAKEBENCH Benchmarking Wind Farm Flow Models	WIND
LIDAR Wind Lidar Systems for Wind Energy Deployment	WIND
Reliability Data Standardizing Wind Turbines Data Collection	WIND
Assessing Enviromental Effects WREN	WIND
Ground Based Testing for Wind Turbines and Components	WIND
Forecasting for Wind Energy	WIND
Wind Energy Systems Engineering Integrated R&D and D	WIND

Activity	TCP
Quiet Wind Turbine Technologies	WIND
Downwind Turbine Technologies	WIND
ExCo Activities	SolarPACES
Solar Thermal Electric Systems	SolarPACES
Solar Chemistry Research	SolarPACES
Solar Technology and Advanced Applications	SolarPACES
Solar Heat for Industrial Processes	SolarPACES
Solar Resource Assessment and Forecasting	SolarPACES
Solar Energy and Water Processes and Applications	SolarPACES
Renewable Energy Technology Deployment	RETD
Enhanced Oil Recovery	EOR
Fluidized Bed Combustion	FBC
Gas and Oil Technologies	GOT
ExCo Activities	DSM
Innovative Energy Services	DSM
Integration of DSM and EE and DG and RES	DSM
Closing the Loop and Behaviour Change in DSM and From Theory to Policies and Practice	DSM
Business Models for a More Effective Market Uptake of EE Energy Services	DSM
High Temperature Superconductivity	HTS
Exco Activities	ISGAN
Smart Grid Case Studies	ISGAN
Benefit Cost Analyses and Toolkits	ISGAN
Synthesis of Insights for Decision Makers	ISGAN
Smart Grid International Research Facility Network SIRFN	ISGAN
Power T and D Systems	ISGAN
Smart Grid Transitions and Institutional Change	ISGAN
Academy on Smart Grids	ISGAN
ExCo Activities	IETS
Industry based Biorefineries	IETS
Industrial Excess Heat Recovery	IETS
Membrane Filtration for Energy efficient Separation of Lignocellulosic Biomass Components	IETS
Energy Technology Systems Analysis	ETSAP
Climate Technology Initiative	CTI
Clean Energy Education and Empowerment	C3E
ExCo Activities	EBC
Air Infiltration and Ventilation Centre	EBC
Cost Effective Building Renovation at District Level Combining Energy Efficiency and	EBC

Activity	TCP
Renewables	
Competition and Living Lab Platforms	EBC
Towards Net Zero Energy Public Communities	EBC
Assessing Life Cycle Related Environmental Impacts Caused by Buildings	EBC
Building Energy Performance Assessment Based on In situ Measurements	EBC
Building Energy Epidemiology Analysis of Real Building Energy Use at Scale	EBC
Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings	EBC
Design and Operational Strategies for High IAQ in Low Energy Buildings	EBC
Energy Flexible Buildings	EBC
Definition and Simulation of Occupant Behaviour in Buildings	EBC
Long Term Performance of Super Insulating Materials in Building Components and Systems	EBC
LowEx Communities Optimised Performance of Energy Supply Systems with Exergy Principles	EBC
Implementation of Energy Strategies in Communities	EBC
Ventilative Cooling	EBC
Business and Technical Concepts for Deep Energy Retrofit of Public Buildings	EBC
New Generation Computational Tools for Building and Community Energy Systems	EBC
Cost Effective Energy and CO2 Emissions Optimisation in Building Renovation	EBC
ExCo Activities	DHC
Annex11	DHC
Annex12	DHC
ExCo Activities	ECES
Integration of Renewable Energies by Distributed Energy Storage Systems	ECES
Thermal Energy Storage for Cost Effective Energy Management and CO2 Mitigation	ECES
Energy Storage with Energy Efficient Buildings and Districts´ Optimisation and Automation	ECES
ExCo Activities	4E
Electric Motor Systems	4E
Solid State Lighting	4E
Electronic Devices and Networks	4E
ExCo Activities plus Heat Pump Centre	HPT
Hybrid Heat Pumps	HPT
Domestic Hot Water Heat Pumps	HPT
Heat Pumps in District Heating and Cooling Systems	HPT
Industrial Heat Pumps and Second Phase	HPT
Design and Integration of Heat Pumps for nZEB	HPT
Heat Pumps in Multi Family Buildings for Space Heating and DHW	HPT
Acoustic Signature of Heat Pumps	HPT
Long Term Performance Measurement of GSHP Systems serving Commercial and Institutional	HPT

Activity	TCP
and Multi Family Buildings	
ExCo Activities	AFC
Electrolysis	AFC
Polymer Electrolyte Fuel Cells	AFC
Solid Oxide Fuel Cells	AFC
Fuel Cells for Stationary Applications	AFC
Fuel Cells for Transportation	AFC
Fuel Cells for Portable Applications	AFC
Systems Analysis	AFC
Modelling of Fuel Cells Systems	AFC
ExCo Activities	AMT
Integrated Surface Technology for Friction Reduction in Engines	AMT
Development of Thermoelectric Materials for Waste Heat Recovery	AMT
Model based Design of Tribological Coating Systems	AMT
Multi Material Vehicle Lightweight Structures and Materials Joining Technology	AMT
ExCo Activities	AMF
Information Service and AMF Website AMFI	AMF
Fuel and Technology Alternatives in Non Road Engines	AMF
Methane Emission Control	AMF
Fuels for Efficiency	AMF
Sustainable Bus Systems	AMF
GDI Engines and Alcohol Fuels	AMF
Real Driving Emissions and Fuel Consumption	AMF
Task Activities	COMBUSTION
ExCo Activities	HEV
Information Exchange	HEV
Accelerated Ageing Testing for Li ion Batteries	HEV
Wireless Power Transfer for EVs	HEV
Home Grids and V2X Technologies	HEV
Electrified and Connected and Automated Vehicles	HEV
Assessment of Environmental Effects of Electric Vehicles	HEV
Fuels and Energy Carriers for Transport	HEV
Small Electric Vehicles	HEV
Battery Electric Buses	HEV
ExCo Activities	BIO
Biomass Combustion and Co firing	BIO
Gasification of Biomass and Waste	BIO

Activity	TCP
Direct Thermochemical Liquefaction	BIO
Integrating Energy Recovery into Solid Waste Management Systems	BIO
Energy from Biogas	BIO
Climate Change Effects of Biomass and Bioenergy Systems	BIO
Commercialising Conventional and Advanced Liquid Biofuels from Biomass	BIO
Sustainable Biomass Markets and International Bioenergy Trade to Support the Biobased Economy	BIO
Biorefining in a future BioEconomy	BIO
Biomass Feedstocks for Energy Markets	BIO

7.2 Methods

ADMN [administration] This method is exclusively used for the activities of the Executive Committee of a TCP. It stands for usual management issues regarding the TCP.

ARES [applied research] This method is defined according to OECD´s Frascati Manual. It describes the original investigation undertaken in order to acquire new knowledge. Simulations and the technical and scientific steering of demonstration projects are also covered.

AWRD [awards] An award is granted on a regular basis. This award has to have an impact also outside this activity.

BASC [basic research] This method covers experimental or theoretical work undertaken primarily to acquire new knowledge. It has to be clearly oriented towards the development of energy-related technologies or services, according to the relevant definitions of the IEA-manual for RD&D statistics.

BEST [best practice] A database covering state of the art, examples of good or best practice or information on benchmarking.

CONF [conferences] Conferences are organised on a regular basis. Typically over 100 participants are attending these events, also from outside the TCP. It is a well-established conference in the resp. field.

CONS [consumer behaviour and behaviour change] Studying the consumer or user is in the centre of this activity. His/her user behaviour is analysed, also questions of social acceptance or relevant social developments. The development of strategies to influence behavioural change is included, too. The rebound-effect also falls into this method.

CORE [cost reduction] Activities explicitly have the goal to reduce costs of technologies or services.

COST [costs] If an activity is allocated to this method, it collects cost data for technologies and services on a regular basis.

DATA [big data, protection of data privacy] This method contains questions dealing with the collection and processing of huge amounts of data, but also issues of data privacy and data protection.

EDUC [education and training] Activities in the field of education and training have been developed and/or provided, including summer schools, webinars etc.

EMSA [energy management systems and audits] Here, energy management systems and audit schemes have been developed or improved.

ENVI [environmental aspects] Environmental aspects (including biodiversity) regarding the technology and its application are covered.

FOIK [first-of-its-kind demonstration] The activity plays a crucial role in the initialisation, development, realisation or monitoring of a first-of its-kind demonstration project.

GHGR [reduction of GHG] Activities encompass the analysis of emissions or the development of strategies to reduce emissions of greenhouse gases.

INTR [market introduction] The focus of these activities is to develop strategies for technologies which are ready for the market. Strategies can target a successful market introduction or to create niche markets.

LCSA [life cycle and technology assessment] Costs over the whole life cycle of a technology are evaluated. This category contains also sustainability assessments and evaluation of technologies and their implications.

MADE [market development and deployment] Following a successful market introduction (see INTR), the next step is gaining higher market shares for already mature technologies. The development of business models and financing tools can support the deployment. Certain measures to develop an already existing market also fall under this category.

MONI [monitoring] Activities under this method collect and analyse data from plants which are in operation. Long term case studies also fall under this category**.**

MRKT [market analysis] Markets are analysed (volumes, demand, willingness to pay etc.). Cost-benefit analysis and the identification of existing market barriers are also covered.

OPER [operational performance] Activities focus on the improvement of the operational performance of technologies and systems. The development of communication standards, dispatch rules, decision making processes, asset management and reliability and quality aspects in general also fall under this category.

OUTR [outreach and raising awareness] This method covers development or application of targeted activities to inform and mobilize society or stakeholders. It also covers activities for regional development and activities for developing and emerging countries.

PLAN [planning] The development or improvement of tools and processes for planning are in the centre of this category.

POLE [policies and legislation] Supporting the development of new and improved legislation and policies is in the centre of this activity.

PROD [products] Activities which fall under this method provide market surveys and extensive product information in a certain field of technology.

PROJ [project database] A database contains an extensive sample of projects or plants. Actualisations are carried out on a regular basis. If the focus is instead of a broad coverage on selected examples, see BEST.

Products which are already on the market are covered under PROD. Analysing the data of a selected set of projects/plant is covered under MONI.

REAS (resource assessment and forecasting] Resources and their availability are in the focus, also the development of tools for their forecasting.

ROAD [roadmaps] Development of multinational roadmaps.

SAFE [safety and health issues] Human aspects of health and safety during the production and operation of a technology are covered here.

SECS [security of supply] Security of supply, but also quality aspects of systems like power grids etc. are covered within this method.

STND [standards] Activities allocated to this method can both carry out surveys on existing standards or engage in the development of new or improved standards.

SYST [system analysis and integration] Interdependencies of a technology in a system are the focus of this activity.

SZEN [modeling and scenarios] New modelling tools are developed under this activity. Alternatively, substantial activities have been carried out to adapt existing models to this technology.

TEDE [technological development] This method is defined according to OECD's Frascati Manual. It covers systematic work which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. Prototypes and pilots are also included in this category.

TEST [pre-standardisation, testing protocols and product testing] Activities cover the development, verification and implementation of testing procedures.

7.3 IEA-Topics

Tabelle 7-1: Energy efficiency

1 ENERGY EFFICIENCY

- **11 Industry**
  - 111 Industrial techniques and processes
  - 112 Industrial equipment and systems
  - 113 Other industry
  - 119 Unallocated industry
- **12 Residential and commercial buildings, appliances and equipment**
  - 121 Building design and envelope
    - 1211 Building envelope technologies
    - 1212 Building design
    - 1219 Unallocated building design and envelope
  - 122 Building operations and efficient building equipment
    - 1221 Building energy management systems (incl. smart meters) and efficient internet and communication technologies
    - 1222 Lighting technologies and control systems
    - 1223 Heating, cooling and ventilation technologies
    - 1224 Other building operations and efficient building equipment
    - 1229 Unallocated building operations and efficient building equipment
  - 123 Appliances and other residential/commercial
    - 1231 Appliances
    - 1232 Batteries for portable devices
    - 1233 Other residential/commercial
    - 1239 Unallocated appliances and other residential/commercial
  - 129 Unallocated residential and commercial buildings, appliances and equipment
- **13 Transport**
  - 131 On-road vehicles
    - 1311 Vehicle batteries/storage technologies
    - 1312 Advanced power electronics, motors and EV/HEV/FCV systems
    - 1313 Advanced combustion engines
    - 1314 Electric vehicle infrastructure (incl. smart chargers and grid communications)
    - 1315 Use of fuels for on-road vehicles (excl. hydrogen)
    - 1316 Materials for on-road vehicles
    - 1317 Other on-road transport
    - 1319 Unallocated on-road vehicles

1 ENERGY EFFICIENCY
132 Off-road transport and transport systems
133 Other transport
139 Unallocated transport
14 Other energy efficiency
141 Waste heat recovery and utilisation
142 Communities
143 Agriculture and forestry
144 Heat pumps and chillers
145 Other energy efficiency
149 Unallocated other energy efficiency
19 Unallocated energy efficiency

Tabelle 7-2: Fossil fuels: oil, gas and coal

2 FOSSIL FUELS: OIL, GAS and COAL
21 Oil and gas
211 Enhanced oil and gas production
212 Refining, transport and storage of oil and gas
213 Non-conventional oil and gas production
214 Oil and gas combustion
215 Oil and gas conversion
216 Other oil and gas
219 Unallocated oil and gas
22 Coal
221 Coal production, preparation and transport
222 Coal combustion (incl. IGCC)
223 Coal conversion (excl. IGCC)
224 Other coal
229 Unallocated coal
23 CO_2 capture and storage
231 CO_2 capture/separation
232 CO_2 transport
233 CO_2 storage
239 Unallocated CO_2 capture and storage
29 Unallocated fossil fuels

Tabelle 7-3: Renewable energy sources

3 RENEWABLE ENERGY SOURCES
31 Solar energy
311 Solar heating and cooling
312 Solar photovoltaics
313 Solar thermal power and high-temp. applications
319 Unallocated solar energy
32 Wind energy
321 Onshore wind technologies
322 Offshore wind technologies (excl. low wind speed)
323 Wind energy systems and other technologies
329 Unallocated wind energy
33 Ocean energy
331 Tidal energy
332 Wave energy
333 Salinity gradient power
334 Other ocean energy
339 Unallocated ocean energy
34 Biofuels (incl. liquid biofuels, solid biofuels and biogases)
341 Production of liquid biofuels
3411 Gasoline substitutes (incl. ethanol)
3412 Diesel, kerosene and jet fuel substitutes
3413 Algal biofuels
3414 Other liquid fuel substitutes
3419 Unallocated production of liquid biofuels
342 Production of solid biofuels
343 Production of biogases
3431 Thermochemical
3432 Biochemical (incl. anaerobic digestion)
3433 Other biogases
3439 Unallocated production of biogases
344 Applications for heat and electricity
345 Other biofuels
349 Unallocated biofuels
35 Geothermal energy
351 Geothermal energy from hydrothermal resources

3 RENEWABLE ENERGY SOURCES
352 Geothermal energy from hot dry rock (HDR) resources
353 Advanced drilling and exploration
354 Other geothermal energy (incl. low-temp. resources)
359 Unallocated geothermal energy
36 Hydroelectricity
361 Large hydroelectricity (capacity of 10 MW and above)
362 Small hydroelectricity (capacity less than 10 MW)
369 Unallocated hydroelectricity
37 Other renewable energy sources
39 Unallocated renewable energy sources

Tabelle 7-4: Nuclear fission and fusion

4 NUCLEAR FISSION and FUSION
41 Nuclear fission
411 Light water reactors (LWRs)
412 Other converter reactors
4121 Heavy water reactors (HWRs)
4122 Other converter reactors
4129 Unallocated other converter reactors
413 Fuel cycle
4131 Fissile material recycling/reprocessing
4132 Nuclear waste management
4133 Other fuel cycle
4139 Unallocated fuel cycle
414 Nuclear supporting technologies
4141 Plant safety and integrity
4142 Environmental protection
4143 Decommissioning
4144 Other nuclear supporting technologies
4149 Unallocated nuclear supporting technologies
415 Nuclear breeder
416 Other nuclear fission
419 Unallocated nuclear fission
42 Nuclear fusion
421 Magnetic confinement
422 Inertial confinement

4 NUCLEAR FISSION and FUSION
423 Other nuclear fusion
429 Unallocated nuclear fusion
49 Unallocated nuclear fission and fusion

Tabelle 7-5: Hydrogen and fuel cells

5 HYDROGEN and FUEL CELLS
51 Hydrogen
511 Hydrogen production
512 Hydrogen storage
513 Hydrogen transport and distribution
514 Other infrastructure and systems
515 Hydrogen end-uses (incl. combustion; excl. fuel cells and vehicles)
519 Unallocated hydrogen
52 Fuel cells
521 Stationary applications
522 Mobile applications
523 Other applications
529 Unallocated fuel cells
59 Unallocated hydrogen and fuel cells

Tabelle 7-6: Other power and storage technologies

6 OTHER POWER and STORAGE TECHNOLOGIES
61 Electric power generation
611 Power generation technologies
612 Power generation supporting technologies
613 Other electric power generation
619 Unallocated electric power generation
62 Electricity transmission and distribution
621 Transmission and distribution technologies
6211 Cables and conductors (superconducting, conventional, composite core)
6212 AC/DC conversion
6213 Other transmission and distribution technologies
6219 Unallocated transmission and distribution technologies
622 Grid communication, control systems and integration
6221 Load management (incl. renewable integration)
6222 Control systems and monitoring

6 OTHER POWER and STORAGE TECHNOLOGIES
6223 Standards, interoperability and grid cyber security
6229 Unallocated grid communication, control systems and integration
629 Unallocated electricity transmission and distribution
63 Energy storage (non-transport applications)
631 Electrical storage
6311 Batteries and other electrochemical storage (excl. vehicles and general public portable devices)
6312 Electromagnetic storage
6313 Mechanical storage
6314 Other storage (excl. fuel cells)
6319 Unallocated electrical storage
632 Thermal energy storage
639 Unallocated energy storage
69 Unallocated other power and storage technologies

Tabelle 7-7: Other cross-cutting technologies or research

7 OTHER CROSS-CUTTING TECHNOLOGIES or RESEARCH
71 Energy system analysis
72 Basic energy research that cannot be allocated to a specific category
73 Other

7.4 Node Properties

Node Type	Property Name	Description
Working_party	Name	String with the short name of the working party. End-use working party is split up into its sub coordination groups.
TCP	Name	Full name of the TCP
TCP	Abbrev	Abbreviation of the TCP
TCP	WP	Working party the TCP is part of. Note that this information is also given by the edges connected between working_party and TCP. However, storing this information also as a property enables easy filtering.
ACT	Name	Full name of the activity
ACT	Task_nr	Official Task or Annex number
ACT	TCP	TCP the activity belongs to (for easy filtering)
ACT	URL	Official URL of the activity (if available)
ACT	start	Start year of the activity
ACT	end	End year of the activity (if already finished)

Node Type	Property Name	Description
ACT	status	Status of the activity (planned/running/finished)
METH	Name	Full name of the method
METH	Abbrev	Four digit abbreviation of the method
METH	class	Category of Methods
Country	Name	Full name of the country
Country	ISO	Two digit ISO code of the country
Country	population	Population of the country in million
Country	Budget	Total RD&D Budget 2015 in m USD
Country	status	IEA membership status (MC - Member Country, AS - Associated Country, CC - Candidate Country, PC - Other status or partner Country)
IEA_Topic	Name	Full name of the IEA-topic
IEA_Topic	Hierarchy	Number, 1 - 4. Describes the level of hierarchy the topic is located (1 = most aggregated level, 4 = most detailed level). Property implemented for easy filtering.
IEA_Topic	Number	Topic allocation code according to the IEA RD&D taxonomy
IEA_Topic	Budget	Total RD&D Budget 2015 in m USD
IEA_Topic	last	Boolean. True if the given topic is the last topic in the hierarchy. Falls if it has more sub-topics. Property implemented for easy filtering.

7.5 Country Codes

Name	ISO	Name	ISO
Australia	AU	Luxembourg	LU
Austria	AT	Malaysia	MY
Belgium	BE	Mexico	MX
Brasil	BR	Monaco	MC
Canada	CA	Morocco	MA
Chile	CL	Netherlands	NL
China	CN	New Zealand	NZ
Croatia	HR	Nigeria	NG
Czech Republic	CZ	Norway	NO
Denmark	DK	Poland	PL
Estonia	EE	Portugal	PT
European Commission	EU	Russia	RU

Name	ISO	Name	ISO
Finland	FI	Singapore	SG
France	FR	Slovak Republic	SK
Germany	DE	Slovenia	SI
Greece	GR	South Africa	ZA
Hungary	HU	Spain	ES
Iceland	IS	Sweden	SE
India	IN	Switzerland	CH
Indonesia	ID	Thailand	TH
Ireland	IE	Turkey	TR
Israel	IL	Ukraine	UA
Italy	IT	United Arab Emirates	AE
Japan	JP	United Kingdom	UK
Kazakhstan	KZ	United States	US
Korea	KR	Venezuela	VE
Lithuania	LT		

7.6 Links

- Permanent link to archive with the raw graph data

  http://documents.energyagency.at/index.php/s/1xDodz26z5BybW8

- Neo4j Graph Database

  https://neo4j.com/

- Gephi Graph visualization software

  https://gephi.org/

8 List of figures

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Andreas Indinger studied Physics at the University of Technology of Vienna. He has been working at Austrian Energy Agency since 2000 and heads the Centre for Research and Innovation. His main topics are R&D-policy and –programmes and he is responsible for surveys on R&D-expenditures. He is one of Austria's representatives in the Steering Group of the European SET-Plan and Austrian delegate and vice-chair of IEA's Renewable Energy Working Party.

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Lukas Eggler studied Renewable Energy Engineering and Management in Freiburg/Germany. He has been working at the Austrian Energy Agency since 2014 as expert for renewable energy sources and energy efficiency. In addition he is head-trainer of the AEA Academy course "Energy performance - indicators and baseline". Currently he is working in various projects on energy system modelling, data analysis and data visualisation.

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Lukas Zwieb has studied Environment and Bio Resource Management at the University of Natural Resources and Life Sciences in Vienna. He has been working at the AEA since 2016 as scientific support and developer. His main emphasis is the analysis of the energy market developments and the respective prices. Additionally, he is part of the development team of the internal database.

ABOUT THE AUSTRIAN ENERGY AGENCY

The Austrian Energy Agency is the national centre of excellence for energy. New technologies, renewable energy, and energy efficiency are the focal points of our scientific activities. The objectives of our work for the public and the private sector are the sustainable production and use of energy and energy supply security. We are an independent think tank that manages knowledge, provides the basis for well-founded decision making, and develops suggestions for the implementation of energy-related measures and projects. We advise decision-makers in politics, science, and the industry on the basis of our mainly scientific work. We prepare political, energy and economic expert opinions, economic feasibility analyses, social analyses, feasibility studies, and evaluations.
The Austrian Energy Agency acts as the National Energy Efficiency Monitoring Body.
www.energyagency.at

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