# TECHNOLOGY MONITOR

*DESIGN OF A REGISTRATION METHOD FOR SUBSIDIZED ENERGY INNOVATION PROJECTS IN THE NETHERLANDS*

*Author:*
Tim Foppen
1510789

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Graduation Committee

| | |
|---|---|
| Professor: | Prof. Dr. Ir. P.M. Herder |
| First Supervisor: | Dr. Ir. S.W. Cunningham |
| Second Supervisor: | Dr. T.E. van der Lei |
| External Supervisor (RVO.nl): | Drs. Ing H. J. Koch |

TU Delft Delft University of Technology

Rijksdienst voor Ondernemend Nederland

# PREFACE

Today, at my birthday, I am finishing this thesis and with that, my time as a student is over. During my bachelor and master I have enjoyed being a student at the most wonderful university of the Netherlands. The people and their attitude is something that is unique to Delft and it is something that I will definitely miss when I will leave the university. Furthermore my time abroad, at the Politechinico di Milano, my roommates, the things I was able to organize and my friends who I got to know during my student time helped me grow up over a period of almost 7 year. All this has taught me a lot about my personal competences and capabilities, making me a different person than I would have been if I did not go to Delft!

For this final chapter of my student time, my graduation, I would like to thank my committee, including Paulien Herder and Telli van der Lei, but especially Joost Koch and Scott Cunningham. Scott you have always provided me with great support and understanding. Taking the time for my questions and giving me the confidence I was doing the right thing. As you helped me through the thesis I think I have been very lucky with you as a supervisor since you are a great person as well! And Joost I would like to thank you for your enthusiasm and help during my time at RVO.nl. With your positive attitude to new things you've stimulated me to do my own thing that was different from what was happening at RVO. I enjoyed the different angles you always proposed for my research and hope I have contributed to your research at the University of Utrecht as well.

Furthermore I specially would like to thank some persons. First of all I would like to  my parents for listening to my difficulties during the thesis, making jokes about it and giving me a kick in the ass sometimes. I would like to thank Rutger: you are an awesome friend and roommate and because we were graduating at the same time, we together encountered the struggles of writing a thesis. Without our endless talks and off course the many coffee breaks I would not have made it buddy :P! Finally I would like to thank Elisabeth, who I got to know during this period of graduation, for her support during the last final bits and pieces ☺.

Tim Foppen

April 16, 2015

# EXECUTIVE SUMMARY

Technological innovation is an important determinant for long term economic growth (Solow, 1956). Porter (1990) argues that technological innovation is the main driver for the competitive advantage of nations, but also regions or companies. The Dutch national government even states that innovation is the beating heart of the economy (Agentschap NL, 2011). For this reason innovation is one of the classic areas in economic policy of governments all over the world.

The latest Dutch innovation policy, the *Topsectorenbeleid (TSE)*, is introduced by the Ministry of Economic affairs in 2011 (Rijksoverheid, 2011). The energy sector is one of the Topsectors. As a sector energy, has been subject to innovation policies for a long time. These policies have been driven by International agreements on $CO_2$ reduction, for instance the 2020 goals of the EU. In the new topsectorial approach the government aims to take into account economic potential to a larger extent when making policies. Due to the long tradition of innovation support throughout the years many innovation policy instruments where created for the energy sector (RVO.nl, 2014a).

Policy alignment is a well-known problem when stimulating innovative technologies. Policy instruments should be aligned and they should, to a large extent, support the same or similar technologies within the energy sector. Misalignment results in the effect that investments are not used efficiently and the economic growth is not optimized. Constant alignment of policy instruments is thus necessary, as well as the resulting alignment of innovation practices supported by policy.

RVO.nl is the public funding agency of the Dutch Ministry of Economic Affairs. As executer of the policy and monitor of its effects, RVO.nl is interested in the question whether and to what extent the technologies that are stimulated within in the Topsector Energy Policy (TSE) are aligned with other instruments. As a case study this thesis will look at the comparison with the Energie Investerings Aftrek (EIA). This comparison is special since the instruments stimulate technologies in subsequent phases of innovation.

| TRL | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Fase | Discovery | | | Development | | | Demo | Diffusion | |
| Onderwerp | Systeem | Functie | Concept | Element | Component | | Product | *Toepassing Exemplaar Markt* | *Gebruik* |

**Figure 1 Phases of Development for Technologies (RVO, 2014)**

The TSE-policy stimulates technologies in research/discovery, development and demonstration phases (RD&D). EIA stimulates the market deployment and diffusion of energy saving technologies (Figure 4 Phases of Development for Technologies (RVO, 2014). Mature TSE-technologies should reappear on the EIA-list. Additionally, incremental improvements to existing EIA-technologies should be reached through RD&D-effort. This should, ideally, be stimulated by the TSE-policy.

Together TSE and EIA should form an aligned combination of policy instruments that stimulate technologies from their discovery in a research laboratory, to their diffusion in society. From the market introduction on, significant returns on public investments can be reached through economic growth, $CO_2$ reduction and competitive advantage due to innovation.

In this research alignment was approached from a technology perspective. This approach is chosen find out whether TSE and EIA policy are aligned in terms of technologies they support. In order to identify consistency and coordination issues related to alignment, a method for technology comparison is required. As a consequence a classification system for the content of technologies and technology project was developed that could be used as an alignment measurement tool. Furthermore this resulted in the following research question:

*How can innovative energy technologies be classified and compared in order to analyze alignment of policy instruments now and in the future?*

This question and approach of alignment requires a classification of the projects and technologies in both instruments based on their technological content. In order to solve the problem a morphological analysis was used as a methodological approach. Next to that the classification issue was separated in smaller issues regarding the technology classification. It embeds the actual classification issue, dealing with hierarchical technologies and dealing with innovation of technologies. First of all in order to make a technology classification system it is necessary to understand how technologies can be described. Product and system design theory describe technologies from a functional and physical perspective (Erens & Verhulst, 1997) (Suh, 1998), as is applied in this research. Furthermore one requires understanding of the hierarchical character of technology and complex technological systems (Murmann & Frenken, 2006). Since technologies can be decomposed into endless hierarchies one has to determine one or more levels of comparison. Finally, since innovation can take place at any level in this hierarchy (Arthur, 2009), (Sood & Tellis, 2005 ) it is necessary that a classification system for technologies is capable to be applied in a more and more detailed setting; in this way future innovations and improvements can be mapped as well.

A literature review led us to theories of product and systems design. Concepts from product and system design created the basis for the method that makes it possible to compare technology projects in the TSE-policy with EIA-policy. As a consequence the classification is approached as an inversed design process. First physical decomposition of products will be done and secondly physical technologies will be assigned to a functional class. This will be done on every hierarchical level. Both will be classified in pre-defined functional and physical classes, which form a strong relation: certain physical classes belong to one or a limited amount of functional classes (and vice versa).

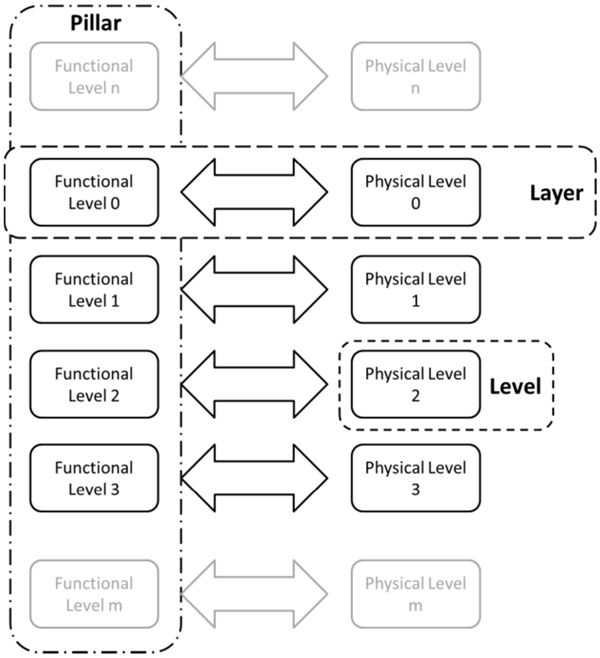


**Figure 2 Conceptual Classification Model**

Approaching the classification as an inversed design process resulted in a conceptual model based on pillars, layers and levels (Figure 2). The functional and physical hierarchies form pillars of classification. Within these pillars multiple levels can be distinguished that correspond to the classification categories. Furthermore the combined levels of the physical and functional hierarchy together form a layer. In order to compare EIA and TSE this research classified technologies along two layers. If necessary these classes can be extended to higher or lower layers, depending on the detail one requires for analysis.

Another part of the conceptualization phase was the development of a procedure to secure that repetition of the classification practice is possible. This procedure extended the original conceptual classification model for analysis of alignment, to a model with a guideline for classification of projects and technologies in RVO. For classification it is necessary to decompose the physical technologies first, before assigning a functional class. This helps to deal with multifunctional cases and furthermore makes it possible to include new data for future analysis.

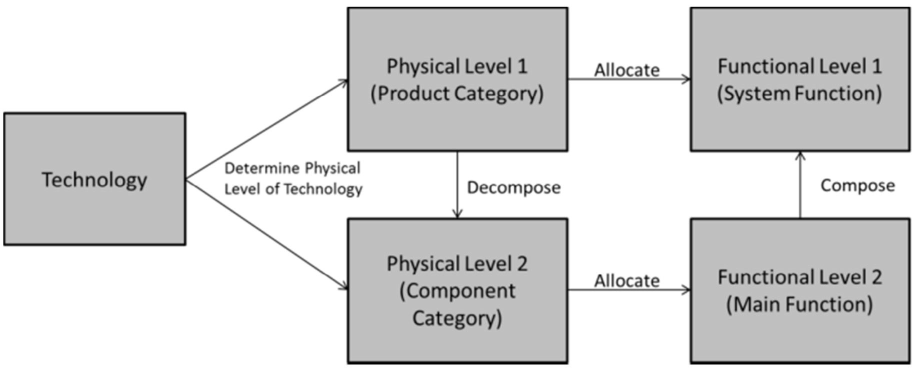


**Figure 3 Application Procedure**

Furthermore the method, including the comparison model and application procedure, enabled us to analyze the current alignment of EIA and TSE policy. The main functional level analysis showed us the most usable results; spread over 4 systems (conversion, production, distribution and storage) 12 functional categories were found to be unaligned within TSE and EIA, 10 were found to have poor alignment and only 4 categories were aligned.

**Table 1 Alignment Analysis Results**

| **Conversion** | | |
|---|---|---|
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Cooling | Heating | Ventilating |
| Isolating | Industrial Processing | Driving |
| Drying | Energy Efficiency (general) | Monitoring & Controlling |
| Lighting | | |
| Reusing Energy | | |
| Efficient Mobility | | |
| **Production** | | |
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Producing Geothermal Energy | Producing Solar Energy | Producing Bio Energy |
| Producing Hydrogen Energy | Producing Fossil Energy | |
| Producing Waste Energy | Producing Wind Energy | |
| Producing Hydro Energy | Producing Energy (general) | |
| **Distribution** | | |
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Managing Energy | Transporting Energy | |
| **Storage** | | |
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Storing Hydrogen | Storing Electricity | |
| Storing Fuels | Storing Heat | |
| Storing Unspecified | | |

Due to this high amount of misalignment, further desk research was conducted. This helped us to understand that his was due to deliberate policy decisions or natural circumstances like existence of a dominant design, an immature technology or policy decision to no longer support a fully developed technology or technology with limited potential. One could thus not fully rely on registration and comparison of project, but should always look for other explanations. Nonetheless it was found that managing energy is the biggest blind spot on the EIA-list. This functional category contains energy management systems that enable the implementation of smart grids.

Evaluation of the classification system made one aware of the aspects that the classification does and does not cover. The classification system is capable to classify the current project of RVO on their technology. This includes the ones without a physical representation in the real world. Also non existing functions can be classified along the same methodology, although this requires slight maintenance over the years. With respect to alignment, it should be clear that only technological misalignment can be measured using the outcomes of the classification system. The analysis will reduce misalignment to a limited amount of functional categories, in which organizational misalignment could play a role. The underlying organizational misalignment in the public funding system cannot directly be measured.

Nonetheless one could conclude that alignment of policy instruments could be studied from a technology perspective. Innovative energy technologies can be compared using a model composed of related physical and functional pillars, using multiple levels and layers, dependent on the detail required for analysis. Innovation can be dealt with within this methodology.

Recommendations of this research are twofold. By performing a study on the alignment of two policy instruments it has been proven possible to study alignment from a technology perspective. Now it is important to implement the methodology and to make it usable for daily practices and decision making. In order to so, recommendations cover aspects of implementation for future usage and improved usability.

As mentioned before, an analysis of alignment gets outdated as soon as new project will be initiated. As new projects occur and the EIA policy is updated, the database that is used for analysis should be updated as well. Therefor it is recommended to implement the registration method in daily practice of RVO employees. Registering projects along this methodology enables RVO to continuously monitor the content of its projects. Secondly in order to maintain consistency in the database it is necessary to appoint someone to be responsible for the content of the database. This person needs to be capable to classify projects, spot inconsistencies in the classification done by other and be able to add new functional or physical categories if necessary. Next to that, as policy makers, funding agencies and research performing organizations can use the information to align their activities, evidence based policy making is of interest of more stakeholders than just RVO. Evidence based policy making based on the registered project content will help to coordinate of research activities and further alignment of these activities.

From a user's perspective it should be understood that a classification system could only work when the users are capable to work with it. User manuals and documented cases are current examples of practices that could help users to understand how to use the classification system. In the future these should be extended by training sessions which help users and designers to improve the method. Therefor it is recommended to put extra attention to the usability aspect. For instance training session could be given or the system could be communicated to users as a tool by which strategic goals like evidence based policy making and decision making could be reached. This will increase the acceptance among both internal and external users to use the system.

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# 1. INTRODUCTION

Technological innovation is an important determinant for long term economic growth (Solow, 1956). Porter (1990) argues that technological innovation is the main driver for the competitive advantage of nations, but also regions or companies. The Dutch national government even states that innovation is the beating heart of the economy (Agentschap NL, 2011). For this reason innovation is one of the classic areas in economic policy of governments all over the world. Effective innovation furthermore includes a process of variation, selection and retention as explained by (Geels, 2002) and substantiated by evolutionary economic theory (Schumpeter, 1934), therefor making it hard to balance policy in such a way that it gives attention to all three aspects.

## 1.1 TOP SECTOR ENERGY

The latest Dutch innovation policy, the *Topsectorenbeleid (TSE)*, is introduced by the Ministry of Economic affairs in 2011 (Rijksoverheid, 2011). With this policy the national government aims for innovation within 9 sectors organized in TKI's (*Topconsortia Kennis en Innovatie*). Within these sectors the Netherlands already performs a world leading role. By appointing the specific sectors for subsidies, the government intends to maintain and extent the current economic advantage through the development of new technologies. These technologies are supported through innovation subsidies, which are divided among innovating organizations and consortia. One could speak of an innovation community (Lynn, Mohan Reddy, & Aram, 1996) of collaborating actors, coordinated by the government, that work on the development commercialization of new technologies.

The energy sector is one of the Topsectors. As a sector energy, has been subject to innovation policies for a long time. These policies have been driven by International agreements on $CO_2$ reduction, for instance the 2020 goals of the EU. In the new topsectorial approach the government aims to take into account economic potential to a larger extent when making policies.

## 1.2 ALIGNMENT OF INNOVATION IN THE ENERGY SECTOR

Due to the long tradition of innovation support throughout the years many innovation policy instruments where created for the energy sector (RVO.nl, 2014a). All applied instruments had different aims of their own. For instance some instruments aim at stimulation of complementary innovation phases, while others focus on a specific group of stakeholders (think of knowledge instituted, SME's or large firms). On top of that the subsidy requirements within the instruments where updated or changed on a yearly basis. This differentiation creates a patchwork of instruments or policy regimes. It is unclear whether the instruments support similar technologies. Furthermore subsidized projects or technologies are hard to compare over different policy instruments. As a result it is hard to align the policies within the Dutch energy sector.

Policy alignment is a well-known problem when stimulating innovative technologies. Negro et al (2012) list it as one of their systemic failures of innovation systems and define alignment as *the consistency of different regulations between policy levels, different sectors and existing and new institutions.* Policy instruments should be aligned and they should, to a large extent, support the same or similar technologies. Without an aligned policy mix, it is hard and takes longer (Hekkert et al, 2007) for new technologies to get to the market and 'pay back' the initial R&D investments. This means that investments are not used efficiently and the economic growth is not optimized. Furthermore alignment is a goal for the coordination of activities within the innovation community. Constant alignment of policy instruments is thus necessary, as well as the resulting alignment of innovation practices executed by innovators.

## 1.3 RVO Case Study

RVO, the Dutch Enterprise Agency executes subsidy regulations and innovation policies for the Ministry of Economic Affairs. The Topsector energy policy (TSE) is one of them. Part of the execution is that RVO has the task to monitor the effect of subsidies in energy innovation. This includes tasks like policy evaluation, analysis and advice for future policy improvements which requires a lot of information about the activities in the energy sector. Efficient information exchange is crucial for coordination (Lynn, Mohan Reddy, & Aram, 1996), but mostly happens through intangible exchange in between actors.

The Topsector expressed its interest to gather information about activities by maintaining a more tangible technology portfolio (Topsector Energie, 2015). This portfolio could be used to report information of the activities and could moreover serve as a decision making support tool, as it helps policy makers to evaluate previous policies and improve future policy frameworks. As a result RVO started to develop a technology portfolio; this should be constantly updated and extended.

Within the portfolio, RVO is interested in the question whether and to what extent the same technologies are stimulated within in the Topsector Energy Portfolio and other instruments. As a case study this thesis will look at the comparison with EIA (Energie Investerings Aftrek, see also Appendix B), which is special since they stimulate technologies in subsequent phases of innovation.

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**Figure 4 Phases of Development for Technologies (RVO, 2014)**

The TSE-policy stimulates technologies in research/discovery, development and demonstration phases (RD&D) (Figure 4 Phases of Development for Technologies (RVO, 2014)). EIA stimulates the market deployment and diffusion of energy saving technologies. Mature TSE-technologies should reappear on the EIA-list. Additionally, incremental improvements (Henderson & Clark, 1990) to existing EIA-technologies should be reached through RD&D-effort. This should, ideally, be stimulated by the TSE-policy.

Together TSE and EIA should form an aligned combination of policy instruments that stimulate technologies from their discovery in a research laboratory, to their diffusion in society. From the market introduction on, significant returns on public investments can be reached through economic growth, $CO_2$ reduction and competitive advantage due to innovation.

## 1.4 Objective of the Research

To answer the question of RVO this research it is aimed to create insight in the alignment of the technologies in TSE-projects and the technologies in the EIA-policy. With this information it is possible to measure to what extent they stimulate similar technologies and to what extent the innovation policy does what it is supposed to do: develop and commercialize technologies. As a result one will be able to identify weak spots policy and coordinate the practices of EIA and TSE better.

In order to analyze alignment, a classification will be created that makes comparison of technologies, stimulated in both instruments, possible. With this classification the development of technologies through TSE and EIA policies should be mapped, compared and monitored. Using the classification one could furthermore track technologies from their original discovery to market application.

## 1.5 Report Structure

The first step in the method design will be an exploration of the research problem in which the key complexities of the research will be identified. The topics of alignment, technology classification, technology decomposition and innovation will be discussed, as well as previous attempts for alignment. Secondly a literature study about will be conducted in order to provide substantial theoretic background for a conceptual technology classification system. This conceptual system will be demonstrated in a case study of EIA and TSE technologies. Finally considerations for future usage will be described looking at the stakeholders that should use the system in the future and related implementation issues.

# 2. Research Problem

This research will be executed within RVO, the Dutch Enterprise Agency. RVO executes subsidy regulations for the Ministry of Economic Affairs. Next to that it has the task to measure the effect of subsidies. A database, consisting of all projects concerning energy innovation, has been build up over the years. Using this database RVO reports to the Ministry of Economic Affairs on the effect of current policy, evaluate previous instruments and advice when new policy is made for the energy sector. Besides that it advices subsidy applicant and judges the project proposals they hand in.

Within RVO the alignment of two technological innovation policy instruments (EIA and TSE) will be researched. It is aimed to do so by comparing the two on a technology level. In this chapter will be elaborated on the main aspects of the research. First the research problem will be described in more detail. I will elaborate on anticipated complexities in the problem exploration section. Furthermore a formal problem statement, research questions, research deliverables, socio/scientific relevance and report structure will be discussed.

## 2.1 Problem Exploration

In the problem exploration complexities of this research will be explored. Four complexities are identified: alignment, technology classification, comparison level and innovation. Within alignment I will elaborate on the difficulty of arranging technological, organizational and policy alignment in general. Classification describes the necessity of a method or strategy to classify technologies. Comparison will discuss the difficulty of finding the right level on which technologies can be compared and innovation will look at the development of technologies over time and the influence this has on a classification. Finally in previous practices, the previous attempts and methods for making a comparison study will be assessed. This will cover their mismatch in making a technology comparison of TSE and EIA technologies possible.

### 2.1.1 Alignment

As discussed in the introduction of this research, policy alignment is a current problem facing RVO with its innovation policies. Still alignment is a very broad term. It is used in many contexts and it is therefore difficult to understand what is actually meant with the term.

Alignment is closely related to terms like consistency in support (Negro, Hekkert, & Alkemade, 2012), coordination of efforts (Kapsali, 2011) or coherence (May, Sapotichne, & Workman, 2006), (Nilsson, Zamparutti, Petersen, Nykvist, Rudberg, & McGuinn, 2012), (Kern & Howlett, 2009) in a policy context. It considers actors that work together on the same topic, this is coordinated through policy. In a technology context alignment refers to convergence of multiple actors (scientists or companies) that, independently, work on the same technology (Korvonen & Kassi, 2011). Also alignment is mentioned when looking at strategic company goals and operational R&D (Gindy, et al., 2008) (Lassenius, et al., 1998). In these cases one looks at the ability of firms to adopt the policy of the strategic board by operational units.

Kathuria, et al (2007) make an important distinction within alignment studies. They distinguish between *vertical* and *horizontal* alignment. Vertical alignment involves the alignment between different hierarchical layers, think of alignment of company goals and operational practices, as mentioned in the previous. Horizontal alignment involves the "*coordination of efforts across an* *organization*" (Kathuria, et al., 2007) on one hierarchical level, for instance between different departments, different policy instruments or multiple companies in a consortium or innovation community.

Alignment is thus most often a coordination effort of activities. This can be influences by hard institutional alignment (Weber & Rohracher, 2012), (Klein Woolthuis, Lankhuizen, & Gilsing, 2005) like written steering instruments (in this case policy) or soft institutional alignment and social institutional alignment like social norms and values, culture or trust (Weber & Rohracher, 2012), (Carlsson & Jacobsson, 1997).

### 2.1.2 Alignment in this Research

In this research alignment is approached from a technology perspective. More specifically this research looks at the horizontal technology alignment (Kathuria, Joshi, & Porth, 2007) of EIA and TSE. This requires mapping and classification of the content within policy instruments in a consistent way. After mapping, a comparison could be made, from which a judgement about hard institutional alignment could follow. Furthermore based on the technology alignment analysis the Dutch Government could improve the hard institutional side of policy and improve the coordination as executed by the policy framework. Soft institutional alignment could follow when solving the hard institutional failure is not sufficient. This will require another toolbox of policy development methods, which require a more process oriented approach.

## 2.2 Technology Classification Approach

As determined in the previous paragraph one needs a means of mapping for comparison. Classification is a method that is often used for allowing comparison (Bailey, 1994). Classification is the means to an end of making cases comparable. If one does not use a classification for comparison, comparison is a very time intensive operation in which all elements have to be compared to all other elements and does not know what aspects to look at when comparing. Furthermore a classification system can be organized in a hierarchical way (Bailey, 1994). In this way the classification excludes some relations (and thus combinations) prior to the comparison. This makes the comparison itself an easier process.

### 2.2.1 Classifying technologies

Van der Bent (2013), in internal research, applied a sectorial approach to classify EIA technologies and TSE-program lines. He used the International Energy Agency (IEA, 2011) classification as a key for comparison. This is a logical comparison but falls short in this this research.

RVO projects are generally classified along their program-line. These program lines and themes (appendix A) changed a lot over the years and are updated every year. Due to the mutable nature of program lines they are not suitable for long term comparison of technology. One thus needs to find an alternative approach that allows translation of policy theme into a common language for which alternative classification is necessary.

The International Energy Agency (IEA) approach can be seen as an alternative for program lines. It makes a distinction in different types of renewables and energy saving technologies. Within the energy saving domain it does distinguish on specific technology characteristics. As an alternative the IEA groups energy saving technologies by the area it is applied in (think of buildings, industry or transport). Since the IEA is a practical guide, it has shortcoming in explaining the conceptual approach of classifying which is necessary to get insight in how to classify. More specified the IEA guide does not help one the classify projects containing multiple technologies; it just describes topics that should be covered as a checklist.

Shortcoming of this combined approach (program lines and IEA) is that it only looks at the application domain of EIA technologies and its related policy program lines. Secondly it does not include individual TSE projects, but only the TKI's they are part of.

This research does include the individual TSE-projects. A similar classification, as the one used by Van der Bent, would be insufficient since it requires more detail and decomposition of the project content. Remaining to the same classification strategy will exclude valuable information from the analysis. Furthermore a deeper technology level requires a different classification for comparison; at some points decomposition is necessary to do so. Many approaches can be used to classify and comparison technologies. Most important is to choose and develop one that is capable of registering technologies over a long period of time, with increasing detail and is not vulnerable for policy changes.

### 2.2.2 Hierarchical Complexity of Technologies

Technologies can be considered complex systems (Sanden & Hillman, 2011). They can be hierarchically decomposed into subsystems and sub-subsystems which are technologies themselves (Murmann & Frenken, 2006), (Baldwin & Clark, 2000). Therefor the second difficulty for this research lies in determining the level of comparison for technologies to which the technologies have to be decomposed. A project, for instance, could consist of multiple products and products could consist of multiple components. This makes that a technology projects can be considered as a complex technology as well, which can be studied on different levels.

In order to compare projects, technologies, products and components (or even sub-components), one or more levels of comparison have to be defined and described a priori. With clearly defined levels it should be ensured that we are talking about two similar things when speaking of "technology". Further research of scientific literature should help to better deal with the issue of decomposing complex technologies by looking at technology's hierarchical structure.

An example of different levels can already be found in the EIA-list. Within the list different heating systems are mentioned as technologies within the domain of heating. Furthermore it is specified with sub-components. Within the TSE-projects a lot of projects that involve effective heating or effective heat exchanging are found, in some cases type of exchanger are even specifically mentioned. The question arises which of the three should be used as basis for comparison? A lot of information exists for some technologies, where others are much harder to specify; this makes determining a comparison level difficult.

### 2.2.3 Innovative Technologies

Innovation is an extra difficulty embedded in this research. Technologies are under development and therefore not yet addressed to specific physical assemblies. As a consequence these technologies are more difficult to compare, since they have not yet developed to fully operational and physical technologies from which they can be decomposed. Nonetheless their conceptual "being", as functional requirement and specifications, can be related to existing technologies in terms of functionality. For this it is assumed that for every technology it is first determined what it has to achieve, before it is known how to achieve the goals set out (Suh, 1990).

Furthermore new technologies will challenge the classification. It requires one to update the system on a regular basis to ensure all technologies can be included. A third part is that innovation will take place on more and more detailed levels as technology matures. This requires a classification to be capable to deal with this.

## 2.3 Previous Practices

Since designing a method, one asks whether and why this has not been tried before. This section gives an overview of previous practices to analyze for alignment and policy improvement. I will elaborate on their mismatch with the problem of comparing EIA and TSE. Subsequently, in the next section, I will introduce the morphological approach used in this thesis based on morphological analysis.

### 2.3.1 Technological Innovation Systems

The Technological Innovation Systems approach (or TIS), specifically looks at improving innovation policy (Jacobsson & Johnson, 2000) (Hekkert et al, 2007). This approach analyses an innovation system by looking at the socio-technical functions that should be performed to reach innovation. It forms a systematic framework for policy making to enhance the capability of actors to jointly develop technologies as well as bringing them to the market. It provides insights in how policy should be adapted in order to better support technology innovation. By doing so it does not focus merely on the technological context but on the policy improvement per technology. One could think of a policy specifically focused at the creation of a market or the diffusion of knowledge for fuel cells.

Innovation system approach identifies weaknesses in the interplay between actors, networks, institutions and technology (Weber & Rohracher, 2012), but in its execution every analysis is limited to one technology at the time. Thus it has to be applied on a technology by technology basis and does not allow one to consider the full energy innovation system. A complete overview of all energy technologies in the Dutch Innovation System by doing technology innovation system analysis is a tremendous effort. It could be used as a method for identifying alignment as a technology specific problem, but is discarded as a method for measuring overall technology alignment.

### 2.3.2 Objectmodel for Innovation

Currently within RVO the object-model for innovation (Appendix C and (Zagema, Koch, & Hoogma, 2009)) is used as a qualitative method to classify technologies within their innovation phases and systems. It is developed as knowledge capturing tool within ALSI and closely related to the TRL methodology (Mankins, 2009). Furthermore it classifies the stage of development that the technology is in by defining objects.

Using this approach the technologies in projects are grouped according to their maturity, with a focus on the innovative aspect of the project. As a consequence the method is not specifically capable of comparing technologies on their overlapping content. Therefor it cannot (directly) be applied for comparison of content and measurement of alignment in policy instruments. Still it could provide a basis for a comparison method looking at the development of technologies over the years. This requires grouping of related projects and topics before such an analysis could be executed and this is where the method is obsolete.

## 2.4 Morphological Analysis

In order to execute this research it is proposed to use a morphological analysis. Morphological analysis is a method used for structured creativity processes and allows one to map the new options in design of a product. Furthermore morphological analysis is a method for mapping the important physical parameters of technology components for practices of product design (Zwicky, 1947). This makes it a method which has been proven to be capable to classify technologies. Generally the method starts with a product, which mostly is an existing configuration of a technology. Secondly this is decomposed into component parts. Options per component are listed and furthermore these optional components are then recombined in alternative configurations. This creates an enormous variety of options from which the designer can choose the most suitable by evaluating the combinations.

For this research the decomposition of existing technologies is important, from this a lot can be learned from morphological approach. The approach classifies along parameters, which can be all sorts of dimensions. According to Ritchie (Ritchey, 2011) morphology is used in scientific disciplines where formal structure is a central issue. Since technologies have strict formal structures, decomposition according to their configuration (or morphology), it is very relevant for technology classification. Furthermore the leading example and development of morphological analysis consists of the decomposition and recombination of a jet engine (Zwicky, 1947).

This description of a so called physical configuration is supported by socio-technical scholars (Sanden & Hillman, 2011) (Carlsson, Jacobsson, Holmen, & Rickne, 2002), technology theorist (Dosi, 1982) (Arthur, 2009) and technology designers (Suh, 1998) (Erens & Verhulst, 1997) (Baldwin & Clark, 2000) (Murmann & Frenken, 2006). It is important to note that the physical configuration is only one area of concern for these authors; they extent their description by aspects as the technology structure and functional structure.

As a consequence the morphological approach does not provide us with any specific insight in what the specific classes should consist of besides physical component parts. In other words the morphological approach falls short in the conceptual description of technology. It describes a technology as a stand-alone structure and it limits the formal description of technologies to the physical domain; it can be assumed there is more background to this, especially regarding the conceptualization of technologies. For instance the description of physical assembly's limits the classification to existing empirical assemblies. This becomes a problem for technologies as described in section 2.2.3. This section describes some of the innovative cases to be classified that do not have a physical representation yet, for which we will look in the functional domain (Suh, 1990).

The next chapter will elaborate further on the topic of technology description also literature from the socio-technical field of innovation systems, the field of technology theory and design theory will be researched to look for alternatives. All fields deal with the same problem of delineating technologies, which they do for their own specific analysis. This causes a variation in views on how to describe and delineate technologies as such.

From the previous sections section it can be concluded no sufficient method exists yet to deal with the complexities mentioned in paragraph 2.2. In section 2.2.1 practical approaches like the classification along project lines or using the IEA Reporting Guide are discarded. Their approach misses methodological background dealing with technology complexity of project and their decomposition in component parts. Still it can be seen as valuable input for determining topics to be classified. Furthermore the objectmodel approach (2.3.2) is discarded. This approach focusses on mapping the development status of a technology, related to its maturity. Therefor it is strong in identifying the innovativeness of a project. Due to the focus on innovativeness, it does not provide means to map the cohesion between projects. Finally the TIS approach (2.3.1) is discarded since it could only be applied on a technology by technology basis to identify whether policy alignment is a problem.

Morphological analysis is a method that is most appropriate to a classification of innovative technologies, but requires adaption by adding a conceptual description of technology in order to deal with innovative technologies. Likewise the classification has to be robust for innovation (new technologies coming into existence) and be able to serve future demands for analysis of alignment. This requires a classification based on a steady conceptual background, which is broader than the physical assemblies as encountered by morphological analysis. For this a literature study will be executed in chapter 3.

## 2.5 Problem Statement

Section 2.1 to 2.4 gave us an overview of the problem. It introduced alignment as an issue in innovation policy and it proposed, discarded and accepted approaches to solve the problem. As a result the following problem statement can be presented for RVO:

*RVO lacks a method that is capable to compare innovative technologies and can provide insight to what extent technologies as stimulated in the Top Sector Energy Policy for Research & Development, are aligned with the EIA list of technologies for market deployment.*

As a start RVO needs a structured approach to compare technologies across policy instruments. Using this, a more detailed analysis and a judgment about the degree of policy alignment can be made. With alignment, the horizontal alignment of TSE and EIA technologies is meant. Two sets of technologies are compared. The relation of technologies to higher policy goals (vertical alignment) is not part of this comparison.

Furthermore in order to compare, clarity on the classification (2.2.1) and decomposition (2.2.2) is necessary. These need to be pre-defined in order to execute the analysis consistently and make repetition possible. Secondly the complexity of innovation needs to be taken into account (2.2.3). Morphological analysis and with an extended description of technology will be used for this.

Since the technologies in both TSE and EIA are updated regularly it is important that alignment can be easily measured in the future as well. Therefor using the similar method for registration, would make this a lot easier. Nowadays the two instrument use separate registration systems. This is inevitable since the policy instruments have different goals. The overlap, for instance the technologies, has opportunities for integration. This also contributes to the wish of having a consistent technology portfolio for all energy innovation projects and policy instruments.

## 2.6 Research Questions

As mentioned before the policy instruments EIA and TSE should form a coherent overall. This includes alignment of policy, finances and technologies. This research focusses on the construction of a method to measure alignment of technologies only. Therefor the main research question for this research will be:

*How can innovative energy technologies be classified and compared in order to analyze alignment of policy instruments now and in the future?*

It should be measured to what extent RD&D technologies, stimulated under TSE (and its predecessors) return in the EIA-list for market deployment and diffusion. Comparing the technologies in the both instruments is therefore an essential step in this research. The development of a method for comparison is necessary for this. Also one should take into account that the comparison is not a static practice. It should be possible to use by users from RVO and be able to classify future new technologies 'developed' in innovation policy.

In order to answer this main question the following sub questions need to be answered:

1. How can technologies be described and compared?
2. How can one choose a satisfying aggregation level for technology comparison?
3. How can be dealt with classification of technologies in different innovation phases?
4. What does a conceptual method for technology comparison look like?
5. What can be told about current alignment of EIA and TSE?
6. How can alignment be ensured in the future?

## 2.7 Deliverables and Practical & Scientific Relevance

At the end of this research we plan to have three deliverables:

1. A classification system for technologies in different energy innovation policy instruments that is robust for technological development and demand for more detailed classification.
2. Application of the classification on the comparison of EIA-list technologies and TSE-projects
   a. Classification of energy technologies in EIA and TSE in accordance on technology level
   b. Comparative analysis of EIA and TSE technologies
3. Recommendations for usage of the method.

Scientific relevance of these deliverables can be found in two aspects. First of all the comparison method will provide a method to deal with policy misalignment in stimulating renewable energy technologies. The method provides the input for analysis that can reveal blank spots of promising energy technologies that are not supported to a satisfying level. This type of analysis can be applied in many other energy innovation policy instruments.

From a more theoretic point of view this research will demonstrate the applicability of functional and physical decomposition in classification of technologies. This classification is used in order to make technologies comparable. Registering technologies using functional and physical aspects creates a consistency in registration practices and the ability to evaluate and analyze energy innovation policy over a longer period of time. As far as we know this has not been done before in technology classification.

Practical and societal relevance will be in the application of the constructed method in the context of the Dutch Ministry of Economic Affairs and its agency RVO.nl. The tools will be used in order to get insight in whether the same technologies are supported in EIA and TSE. Furthermore it will allow policy makers to search for a level of alignment to a level they find relevant. This relevance could differ per technology. Using the systematic registration allows them to differentiate in support of different technologies.

Secondly this method for technology comparison can be used to compare other instruments and technology databases like the SDE regulation. In this way all energy technology related databases of projects can be merged and more instruments could be compared. The combined data can be used as support for monitoring all technology developments within the different instruments, therefor being capable of doing a more integrated analysis to support decisions related to new policy instruments.

Finally the methodological approach can be used and applied by a larger group of users than current practices. The process of registration should be understandable by more than experts and furthermore makes the registered data more consistent. As a result the database of the technology portfolio will be better of quality, better maintainable and supported by a broader range of users. This also ensures the future use of the method.

## 2.8 Outline of the Research

As can be derived from the previous paragraphs the structure of this report will be as follows:

Chapter 1 & 2 we have introduced the problem encountered in this thesis and the context the problem is part of. Chapter 3 consists of a literature review that will help us to answer the three first sub questions. It will give increased insight in what technologies are, how they are structured and what technological innovation is in an academic and theoretic context. Chapter 4 provides us with a more practical and conceptual model for technology comparison based on the theoretic insights of chapter 3. This makes it more robust for future problems regarding innovation and more detailed classification.

Chapter 5 will operationalize the conceptual structure into categories that are applied in the classification. Chapter 6 elaborates on the application procedure which is necessary to make the classification repeatable and come to a consistent registration of technologies. Chapter 7 will provide real world examples of the application of the procedure and categories. Standard cases and complicated cases are discussed as well as remedies to solve them. Chapter 8 reports the actual results of the comparison. It is a demonstration of an analysis based on the designed methodology. Based on this conclusions will be made on the alignment of EIA and TSE policies. Chapter 9 describes the future usage of the method. It looks at the connection of the method with the strategic goals for energy innovation policy in the Netherland.

Chapter 10 evaluates the method as it is developed, the results it produced and the future problems for implementation. Evaluation will be followed by conclusions, recommendations and reflection in chapters 11 and 12.

# 3. THEORY

In the previous paragraph three key issues have been identified as being part of this research: Defining technology comparison level, choosing a technology comparison strategy and dealing with technologies in different innovation phases. The issues have been briefly discussed in section 2.2. Also morphological analysis (section 2.4) has been proposed as a research methodology to deal with them. Still in order to even better understand the issues and their complications a literature study will be executed with the following goals:

- Understanding how technologies can be described and thus can be compared.
- Understanding hierarchical structure of a technology influences the determination of an aggregation level for comparison.
- Understanding innovation and its influence on comparison and classification of technologies.

For understanding how technologies can be compared this literature study will look at different views on technology. Articles from the field of socio-technical innovation systems, complex technical systems, systems architectures and product architectures are compared on their definition of technology. All these literature streams describe technologies and innovation, but focus on different aspects when studying them. Therefore they have different views on what is a technology. These views will be assessed on their usefulness to provide a classification strategy.

Secondly the literature does not only differ in the way they describe technologies, also they choose different hierarchical levels for their analysis. A better understanding of technology hierarchies is necessary to choose a level of analysis for this research.

Next to this, the literature on innovation and the development of technology will be studied. Since the comparison includes projects in different stages of development, it is necessary to know the literature that describes this development process.

## 3.1 DESCRIBING TECHNOLOGIES

Technologies and technology development can be described and studied in many different ways. This paragraph will discuss possible approaches.

First of all, within innovation policy land, socio-technical approaches are wide spread. Socio-technical approaches, as the name says, do not only look at the technology itself; they also embed the social and actor oriented elements of the innovation process. Hekkert et al (2007), Jacobsson & Johnson (2000), Carlsson et al (2002) are authors that embody the innovation systems literature. They describe innovation systems as the networks of actors, institutions and technology fields doing innovation together in a technological innovation system (TIS). Furthermore they analyze these systems along a set of functions. Delineation is a problem for this kind of analyses. Carlsson et al (2002) describe technologies as competence blocks, knowledge fields or products/artifacts in an attempt to give TIS-scholars means of system delineation.

Sanden & Hilmann (2011) build upon the innovation system approach for their model of technology interaction. They try to bridge innovation systems literature with literature about technology systems in order to describe overlap among technologies. For this purpose they conceptualize technologies in three dimensions: conceptual dimension, material dimension and organizational.

Technology transition literature (Geels, 2002) conceptualizes transition processes and innovation as the interplay between niches, regimes and landscapes: niches accumulate and gain strength to change higher level regimes. Technologies, in the view of Geels, fulfill functions.

Continuing on the search towards description of technologies I followed the path of Sanden & Hillman and studied the literature about technology systems. Murmann & Frenken (2006) and Baldwin & Clarke (2000) describe technologies as part of a larger technological system. Next to that a technology itself consists of multiple technologies as well and is thus a technological system of its own. Furthermore they distinguish between functional or task structures, artifacts and artifact structure and a third description talking about design structure or operational principles.

With the idea of designed technologies for a purpose, one ends up studying product and system design theories. Suh's axiomatic design theory for systems (Suh, 1998) is leading in the field of system architectures. Suh looks at a functional and physical domain, which are connected by technology modules. Also Erens & Verhulst (1997) use a similar approach in their theory about product architectures: they describe functional, physical and technology domains (Figure 5 Product model (Erens & Verhulst, 1997).

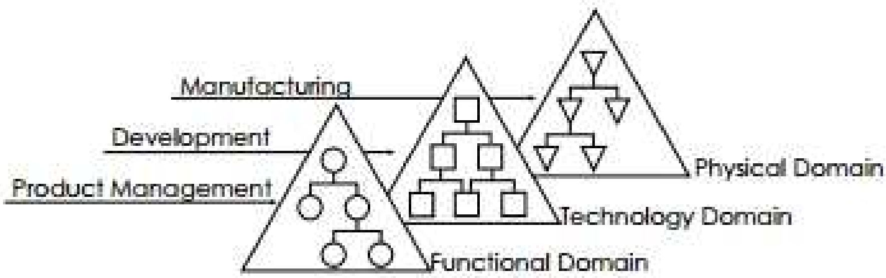


**Figure 5 Product model (Erens & Verhulst, 1997)**

Within both design theories a "technological" approach is mentioned: Erens & Verhulst (1997) embed it as an independent hierarchy and Suh (1998) describes it as technology modules. It is used to understand the interaction between different parts of the technology. The actual decomposition in modules (ether in a module-junction diagram or hierarchy) is dependent on the choices the designer makes when translating the functional hierarchy to the physical hierarchy: Do I put a single functionality in one module or do I integrate multiple functionalities (of one level) in the module? This relation is also hierarchical and takes place in between the categories in one single level in the related physical and functional hierarchy.

Brian Arthur, in his book "*The Nature of Technology*" (2009), describes technologies from a more descriptive perspective than technology designers. Although he agrees with the functional and physical properties, Arthur goes more in depth about 'what is behind' the technology. He describes technologies as self-creating and evolving from itself. Arthur describes the natural phenomena that are the basis of any technology and the technological principles that are used to '*capture*' natural phenomena. In this way he distinguishes application fields like informatics, electrical or mechanical engineering.

Dosi (1982) distinguishes technology paradigms. These paradigms have a large similarity with the fields described by Arthur: "technology in this view, includes the perception of a limited set of possible technological alternatives". Therefor technologies develop along a limited amount of possible trajectories. Translated and combined with Arthur's proposition, Dosi means that, depending on someone's background in different engineering disciplines, he or she will solve a technological problem using the knowledge he knows from previous experiences. An electrical engineer will solve the problem using electrical engineering principles and an informatics engineer will use informatics engineering principles. Knowing this it is possible to categorize technologies along familiar principles, paradigms and phenomena.

Finally the TRIZ-methodology goes even beyond the distinction of paradigms and engineering fields. This methodology, developed in the former Sovjet-Union, distinguishes 39 '*conceptual principles of innovation'* (Savransky, 2000). These are based on patent-data and the argument is that all innovations can be described using one or more of these conceptual innovation principles.

**Table 2 Definition of technology literature**

| Author (s) | No distinction | | |
|---|---|---|---|
| **Hekkert et al** | *Technology can be seen as the knowledge it embodies* | | |
| **Jacobsson & Johnson** | *Technical competence* | | |
| **Geels** | *Technology fulfills functions* | | |
| **Sanden & Hillman** | *"Socio-technical system made up of heterogeneous elements such as physical objects, organizations, knowledge and regulations. Further these elements are organized in value chains"* | | |
| **TRIZ** | Conceptual principles of innovation | | |
| **Sood & Tellis** | Technological change on three aspects | | |
| **Henderson & Clark** | Four types of technological innovation depending on the level on two dimensions | | |
| **Author (s)** | ***Functional view*** | ***Physical view*** | ***Technology view*** |
| **Carlsson et al** | Competence block | Product or artifact | Knowledge field |
| **Sanden & Hillman** | Conceptual dimension (what they ought to do) | Material dimension | Conceptual dimension (what they are able to do) |
| **Murmann & Frenken** | Functional (sub)systems | Artifacts | Operational principles |
| **Baldwin & Clark** | Task structure | Artifact structure | Design structure |
| **Suh** | Functional requirements (functional hierarchy) | Design parameters (physical hierarchy) | Technology modules |
| **Erens & Verhulst** | Functional domain | Physical domain | Technology domain |

| | | | |
|---|---|---|---|
| **Arthur** | Means to fulfill a human purpose | Assemblage of practices and components | Collection of devices and engineering practices available to a culture |
| **Dosi** | - | Physical devices | Practical and theoretical know-how, methods, procedures and experiments |

All previously mentioned authors have different ways of describing technologies and often mention multiple ways. Afterwards they position themselves depending on their research focus. This can be either designing products, describing dominant designs, mapping actor networks and institutions in a technological innovation system or understanding conceptual principles and phenomena behind technologies. Table 3 shows an overview of descriptions of technologies and tries to map them consistently over functional, physical and technological dimensions.

Design oriented approaches (Murmann & Frenken (2006), Baldwin & Clark (2000), Suh (1998), Erens & Verhulst (1997)) focus on the break-down of technologies in functional and physical hierarchies for design practices. Arthur (2009), Dosi (1992), Sanden & Hillman (2011) and Carlsson et al (2002) put more emphasis on the description of technologies in a more conceptual way. Both views can be considered as a basis for a comparison, though the design oriented approach, using physical and functional decomposition, forms the most practical application for mapping technical components and products. Dosi and Arthur, who put emphasis on the principles behind the technology, have more practical application when mapping (fundamental) scientific research, since this often does not embed clear physical or functional parts yet.

The functional and physical approach can be extended using modular description of technologies including module interactions and information streams in a third 'technology' view. For the goal of evaluating and monitoring technologies, instead of design of products, this view is less relevant. It focusses more on the design process, which is often fuzzy and dependent on choices of the individual designer or firm and requires looking at interaction between functions and components. For monitoring and evaluating it is more important to have insight in the start- (functional) and the end (physical) properties of a technology. Decomposition of technologies can provide in the remaining necessities and are elaborated on in the next section.

## 3.2 Hierarchical Structure of Technologies

As discussed; technologies are hierarchical structures. This section will elaborate on these hierarchies and does so along the usage and description of various authors.

Sanden & Hillman (2011) describe technologies from the perspective of upstream and downstream value chains they are part of. Technologies can be decomposed both upstream and downstream hierarchies using the question 'how it can be made' and 'what it can be used for'. This can relate the technology to a higher order system or to its subsystems.

Murmann & Frenken (2006) argue that technologies exist of systems, subsystems, sub-subsystems. Hierarchies, for them, are necessary to better understand this complexity of technologies variations in physical assemblies and the existence of dominant designs. Often they consist of local optima and this local optimum structure can be found in every system, sub-system or component. Therefor one can speak of a nested hierarchy of complex systems with a large degree of self-similarity. Furthermore Baldwin & Clark (2000) distinguish in a task, design and artefact structure or hierarchy. They continue on this by describing modular innovation of subsystems instead of innovation of the system as a whole.

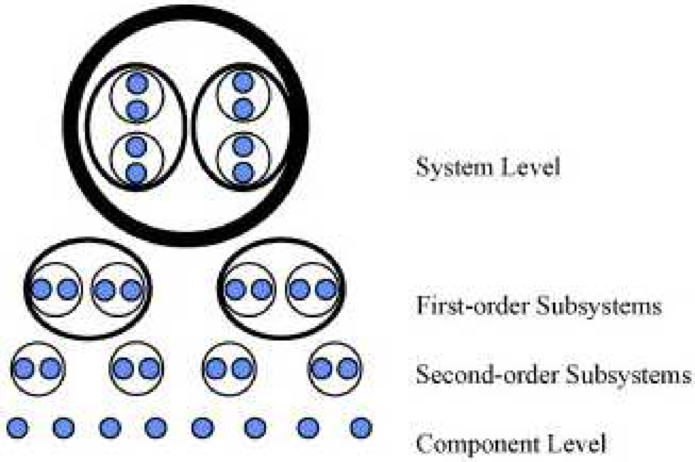


**Figure 6 Nested hierarchy of systems (Murmann & Frenken, 2006)**

Designers of technological products and systems make use of interrelated functional and physical hierarchies. According to Erens & Verhulst (1997) building a product from a number of components is called a product-architecture. Products are thereby hierarchically related when looking at the sub-components they contain. What is called a product and what is called a component is dependent on the level of analysis one chooses.

Suh (1998) describes technological systems as a configuration of all predefined functional requirements (FR's), design parameters (DP's), process variables (PV's) and constraints (C's). He furthermore distinguishes four domains for design; customer, functional, physical and process domains of which the functional and physical domain can be decomposed hierarchically. Functions are decomposed in a hierarchical way and are defined as "*the minimum set of independent requirements that the design must satisfy*". Furthermore they are related to components in the physical domain, as a method for checking a consistent design on its predefined functions and vice-versa, this process is often a zigzag.

In design theories there is a lot of interrelation of functional and physical hierarchies. Designers zigzag between hierarchies and levels in order to check consistency of their technology. They do so in their own specific way, putting emphasis on what they find important, as well as their clients. This causes a variety of products and components on the market, which are functional substitutes.

Concluding, one can see none of the authors specifies a single hierarchical level, but use multiple instead. They do so because the hierarchies in products and components are often interrelated, as well as the functional and physical hierarchy. The innovation of a lower level component causes the adaption all through the hierarchy; the same counts for innovation of higher level components or products. This property also forms the basis for many innovation theories (as discussed in section 3.3). Also functional and physical hierarchies help designers to structure their design process. All designers within one field use the same set of functions for the design of their product: variance occurs when cognitive thinking process vary between designers (the one designer interpreters this function differently from the next), causing functional similarity and substitution.

## 3.3 INNOVATION

As a third issue technological innovation is discussed. Since RVO is dealing with innovative technologies within their policy instruments, one should be aware of the complex process of innovation. Technological innovation is often incremental. Radical innovation is often only radical from the viewpoint of a single economic sector or a large timeframe. Both socio-technical and more technical oriented approaches acknowledge this incremental development of technologies.

Socio-technical scholars discuss innovation, when they talk about accumulation of technologies (Geels, 2002) and transition processes build-up out of the interaction of different technology innovation systems (Hekkert et al, 2007). This perspective studies the role of networks of actors and institutions in this process and the interplay between multiple actor levels (niches, regimes and landscapes).

According to Murmann & Frenken (2006) innovation takes place at all levels of the technology hierarchy. Depending on the level of analysis this can be categorized as radical or incremental innovation. It is argued that the higher in the system hierarchy an innovation takes place, the higher the impact on the system performance. This explains why, distinguishing between radical and incremental innovation depends on the delineation of the system. This can be best explained by their final model in the figure below where the hierarchical model of technologies as nested hierarchies is combined with the technology cycles model of (Henderson & Clark, 1990). As a result innovation takes place in any level of the system hierarchy, all following the same pattern of technology dynamics.

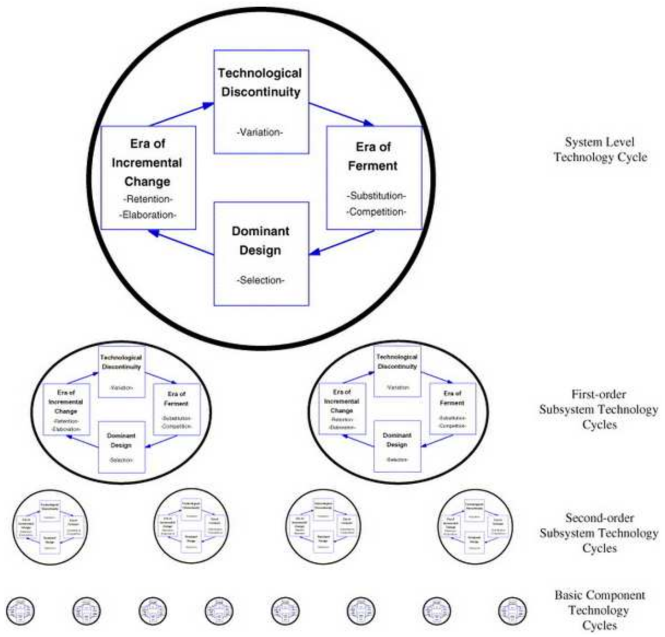


**Figure 7 Nested hierarchy of technology cycles (Murmann & Frenken, 2006)**

Arthur (2009) speaks of structural deepening of a technology. He describes the process of iterative problem solving with a technology: By adding sub-systems to reduce negative impacts or enhance positive effects the technology gets more complex over time. This way of innovation has limitations:

once a single principle reaches his adaptive stretch, novel principles need to be invented in order to improve performance. This often causes revolution and re-domaining of technologies

Sood & Tellis (2005 ) describe the evolution of technologies and put emphasis on types and levels of innovation, going from ordinary (or incremental) innovation towards radical innovation. They conceptualize innovation on three levels: platform innovation, component innovation and design innovation. This relates to the four types of innovation as presented in the framework of Henderson & Clark (1990) (Table 3 Innovation framework as proposed by Henderson & Clark (1990)).

**Table 3 Innovation framework as proposed by Henderson & Clark (1990)**

| Linkages between core concepts and components | Core concepts | |
|---|---|---|
| | Reinforced | Overturned |
| Unchanged | Incremental innovation | Modular innovation |
| Changed | Architectural innovation | Radical innovation |

Technological changes thus evolve at different levels of the technology hierarchy. Designating technologies as radical or incremental innovations is dependent on the context and delineation in which a technology is analyzed.

One could notice that new principles can occur in a technological system. This causes that new functional and physical technologies are created over time; these are often created through changes in the lowest hierarchical level or as a zigzag between physical and functional hierarchies (section 3.2), within the current principles.

## 3.4 Conclusions from Theory

In this chapter literature from many technology and innovation backgrounds is studied in order to understand how technologies are described and thus can be compared. Literature related to the hierarchical structure of technology is studied in order to determine a level of analysis for comparison. And, in order to understand the influence of technological development on comparison of technologies, stepwise approaches to technology maturity and innovation processes are studied. In this section the knowledge from the previous sections will be summarized and related to the next chapter (conceptual morphological structure).

In this research it is most convenient to describe technology from a system and product design approach. The design approach describes both functional requirements and physical assemblies of technologies as they go through a design process. This will also be done in the classification in this research: We are mapping subsidized projects which are spending resources in order to design and develop physical artifacts according to pre-defined functional requirements

Secondly this approach is chosen since it allows technologies to be decomposed in hierarchies. This subsequently solves a problem of comparing innovative technologies, as they develop through different levels of the physical and functional hierarchies.

Describing technology as technology modules or technology hierarchies is not considered appropriate. For the categorization of technologies it is not necessary to add this third approach;

multiple functional technologies can be described in extra categories (same level) or distinguished on a lower functional level. Module description is only necessary when building the technology; this requires understanding the interactions of multiple functions and components. In a government context, where the goal is analyzing and monitoring technologies, this is not relevant information.

Interrelation between categories on one single level can be done using alternative methods. Although this falls out of the scope when comparing EIA- and TSE-technologies, these alternative methods (technology paradigms, technology platforms or technology phenomena & principles) can be used to evaluate technology transition over the long run. For this research we accept that technologies based on new principles will occur. As a consequence they challenge the existing functional and physical categories and thus reiteration of the classification system will always be necessary.

Within the hierarchical approach finding the ‘right’ level of comparison has proven to be a hard task. Hierarchies are seen as ether sequenced steps in value chain, nested hierarchy of interrelated local optima or multiple hierarchies as domains for product and system design. Consequently all studied authors speak of multiple levels or hierarchies when describing technologies.

Next to that innovation literature distinguishes multiple levels of innovation. It couples the hierarchical approach to describe innovation in different parts of a technological system. It can either be innovation by design, components or introducing a new principle and depending on the level in the hierarchy on which the innovation takes place there is variation on the impact.

Furthermore innovation, technological development and maturity are complex phenomena, which make decomposition and classification of technologies a hard practice. Different types of innovation are distinguished (incremental, radical, modular and architectural innovation). All depend on delineation of the technology system (or level) and timeframe which is chosen. This makes that it is very important to determine the starting point of decomposition and develop a procedure that guides the decomposition and classification steps.

In order to guide the decomposition and classification procedure it is proposed to not choose a single level of comparison beforehand, but to compare technologies on multiple levels. The procedure will include looking at both physical and functional aspects. Within this procedure one should always check within in the hierarchies whether the classification takes place on similar levels within one layer of the functional and physical hierarchy.

To conclude, the classification model will be based on two related pillars: a functional hierarchy and a physical hierarchy. Within these pillars multiple levels can be identified which are reached through decomposition using a procedure to ensure consistency. In between the pillars, layers can be identified which relate the functional and physical aspects of a technology.

# 4. Conceptual Classification Model

We have now concluded that a classification system is necessary for the comparison of innovative technologies. Such a classification system will consist of both a functional and a physical pillar. It also includes multiple hierarchical levels in order to make sure future technologies can be embedded and the delineation of technology is done following a standardize procedure.

In this chapter we will describe the conceptual model used for the classification of the technologies: In order to classify the technologies the process of product design will be inversed. This means we are going from physical technologies towards functional technologies. Conceptually this can be done on endless repetition of defining new hierarchical functional and physical levels and layers. In practice only a handful of levels and layers can be useful. The next chapter it will determine which exact levels and categories will be used for comparison of EIA and TSE

## 4.1 Classification Procedure using an Inversed Design Process

Technology can be described in multiple ways as can be found in Table 2 Definition of technology literature. One distinction is by looking at technology from a functional and physical domain (Suh, 1998). Suh (1998) elaborates on the fact that both the physical and functional domain are made up by separate hierarchies. In these hierarchies functional goals are related to physical artifacts by means of a technology. Erens & Verhulst (1997) also speak of a technology hierarchy; this hierarchy is not considered in this concept.

Both authors use these hierarchical views for design of products. They describe the translation from the functional domain to physical domain as a chaotic design process. In this process the eventual outcome is both dependent on the original functional structure and design choices made when relating functional requirements to physical components. This explains the variety in physical products that can fulfill identical (high level) functions. Think, for example, of the many products one could use to provide energy production, heating or lighting. But also within a group physical components or products a variation can exist due to added functions

For this research it is actually necessary to systematically map commonalities of technologies on the one hand and the variation of technologies on the other hand. In order to compare and combine the TSE and EIA technologies therefor both functional and physical classes are introduced. Using both functional and physical classes also comes with the advantage that it can tackle the problem of variation through the usage of different names for the same technology; a technology which is different by its brand name is not a real variation since it fulfills identical function and is an identical physical artifact to its competitors. Also physical artifacts show more variation than functional requirements. Therefor functional classes are capable of classifying technology families and physical classes are able to distinguish the components within one functional class.

Classification is therefore approached as an inversed design process. First physical decomposition of products will be done and secondly physical technologies will be assigned to certain functional requirements on every hierarchical level. Both will be categorized in pre-defined functional and physical classes, which form a strong relation: certain physical classes belong to one or a limited amount of functional classes (and vice versa). This procedure is further elaborated on in Chapter 6: Application Procedure.

## 4.2 DEFINITION OF PHYSICAL AND FUNCTIONAL

Before the conceptual hierarchies are introduces the definition of both physical and functional will once more be discussed. To a large extent the definition is based on the work of Erens & Verhulst (1997) and Suh (1998). In this section I will recapture their definition of physical and functional as well as the presenting the definition used in this thesis.

According to Erens & Verhulst the physical hierarchy consists of "*the consistent description of a system's part and assemblies*". It describes the physical realization of a system and is strongly related to de construction of a product and can be decomposed in physical components. Suh describes design parameters in the physical domain as "*physical parameters, parts or assemblies*". In this research one speaks of physical technologies when the technology is either an existing product or component within a product.

Functions are described by Erens & Verhulst as "*functional requirements ,..., primarily listed in the Requirements Specifications in a textual form*". For Suh, functions or functional requirements form *"the minimum set of independent requirement that completely characterize the functional needs of a produc*t". In this research functions are used as the conceptual description of what (a group of) technology should do.

Based on these definitions, the physical and functional hierarchies will be described in the conceptual model and operationalized in the next chapter (Physical and Functional Levels ).

## 4.3 CONCEPTUAL CLASSIFICATION MODEL

As mentioned several times before, the classification of technologies in this research will be done along multiple levels using multiple hierarchical pillars and related layers. Multiple levels are necessary to deal with the innovative character of technologies: as technologies evolve over time, they are applied in increasingly bigger technical systems (Murmann & Frenken, 2006) (Sood & Tellis, 2005 ) or are extended by increasingly more complex structures, called structural deepening (Arthur, 2009) (as mentioned in section 3.3.1).

Figure 8 displays an overall model for classification of technologies. It shows the possibility to extent the model endlessly in both upward and downward aggregation levels. The figure shows an endless sequel of interrelated functional and physical levels. In theory this allows users to break down technologies to the smallest parts possible (functional and physical level m), or, on the other side, highest aggregation level possible (functional and physical level n). This makes that it is possible to classify and compare technologies that are currently in early innovation phases and not specifically assigned to a higher level function or physical artifact. This only requires one to adapt the procedure that is basis for the classification.

The focus of this research is in the application of a classification model for the comparison of EIA - technologies and TSE technologies. Therefore, in a static comparison, it is necessary to give a definition to each comparison levels within the conceptual model. In the next chapter these definitions will be given for level 0, 1, 2 and 3. Layers will furthermore be defined using examples in both the functional and physical hierarchy. Pillars are distinguished by the definition as given in section 4.2.

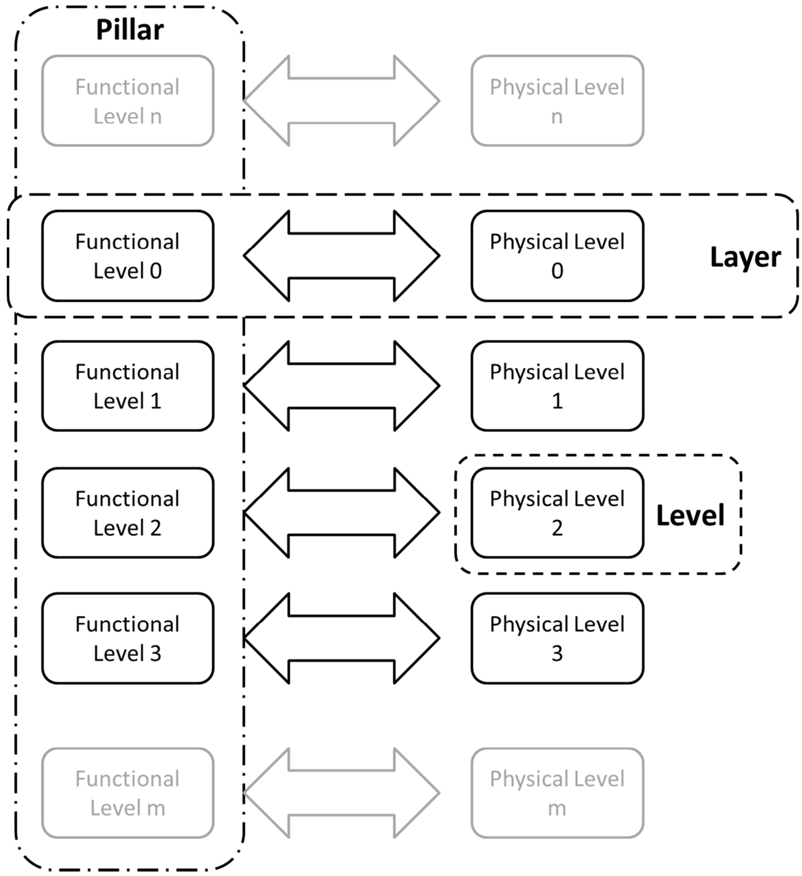


**Figure 8 Conceptual Classification Model using Related Physical and Functional Hierarchies and distinguish in pillars, layers and levels.**

This also touches the scientific relevance of this study: by showing the model is applicable not only for the comparison of EIA and TSE technologies. Instead it can be adapted to any set of energy technologies, independent of the level of innovation, the level of detailed that is available and the policy instrument it is included in. In section 7.3.2 Heat Recovery Ventilation) I will provide evidence for this claim by giving examples of the classification of EIA technologies that have a more detailed description.

In order to structure the classification for this research a formal procedure is added to reduce the classification effort from endless to a two layer/level classification. One will need the classification of all levels within the two layers to get towards the right classification of a technology. Between layers decomposition steps are necessary. One can extent this procedure by decomposing technologies in new layers on higher or lower aggregation levels. Nonetheless this will require one to specify and delineate these levels before applying them.

Although the general classification will be an inversed design process, going from physical artifacts to functional requirements, there are cases where functional requirements are more classifiable. These cases are referred to “immature” technologies that are under development and are not a physical artefact or component yet.

# 5. Physical and Functional Levels

In the previous chapter the conceptual basis for a classification of innovative energy technologies was given. The model is a combination of a physical and functional hierarchy. This chapter describes the operationalization of these hierarchies by discussing four levels and giving a definition of the technologies that should be categorized on that level. In order to clarify this chapter contains a lot of examples. Next to that, both hierarchies are closely related, the third part of this chapter elaborates on this relation.

## 5.1 Physical Hierarchy

A physical hierarchy describes technologies from the configurations and assemblies in which they are embedded. This can be done on multiple levels. Depending on the level of choice a technology is categorized by application area, product, component or sub-component. Since these levels can be interpreted differently from person to person, I will elaborate on the definitions used in this research.

Within the different levels one can ask the question "what do I put in this *application area/product/component/*?" to go down in the hierarchy and "In what is this *sub-component/component/product* embedded?" to go up the hierarchy.

**Table 4 Physical Hierarchy Definitions**

| Aggregation Level | Name | Definition |
|---|---|---|
| **0** | Application Area | Logical grouping of products in Industry, Residential Buildings or Transport |
| **1** | Product | Shell in which the technology is embedded |
| **2** | Component | Technological systems within a shell which is a product or which can be placed in a product, often an apparatus or installation |
| **3** | Sub Component | Piece of hardware with largely internal interaction and as part of a technological system |

### 5.1.1 Level 0: Application Area

The application area categorizes technologies on a high aggregation level. All technologies, applied in the same group of economic activities, are within one category. These categories are seen as energy intensive and the names of the categorization are based on the reporting guide of the International Energy Agency (IEA, 2011). The IEA distinguished by three categories:

1. *Industry:* Centralized production facility that produce a tangible good from ground resources or half fabrics and are specifically designed to do so. This includes advanced techniques and processes, as well as equipment and technical systems.
2. *Residential and Commercial buildings, appliances and equipment:* Buildings used for working (often in service setting), living, and recreation, aimed at the improved design of buildings as well as embedding new equipment in order improve the energy efficiency of a building.
3. *Transport*: Units used for the transport of people or goods both on the road and off the road.

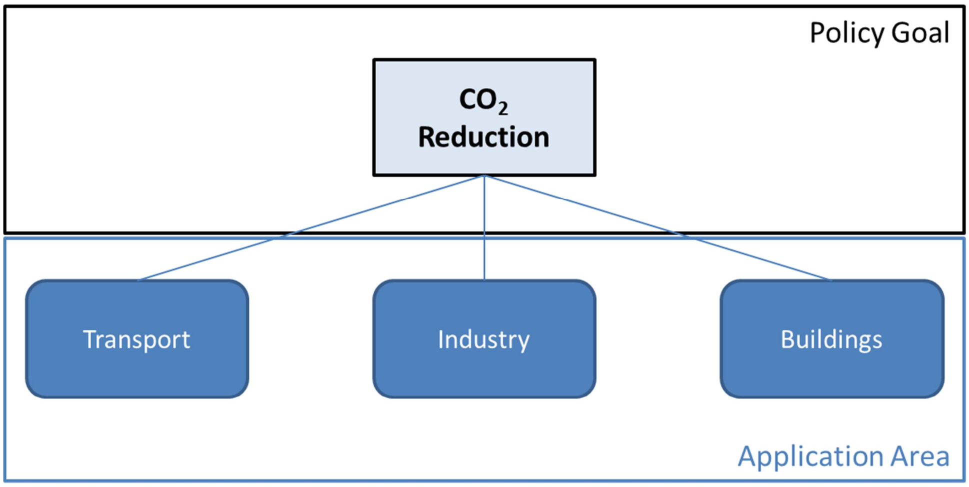


**Figure 9 Relation between Policy Goals and Application Area**

The application area can be used to measure $CO_2$ reductions on a high aggregation level. It explicitly does not tell through which technologies or in what configuration this reduction is realized.

### 5.1.2 Level 1: Products

The product level describes the product or casing, in which a technology is embedded. A product can be seen as the shell in which a technology is used or applied. Of course the shell itself includes technologies as well but these fall out of the energy system and are therefore seen as stable factors over time. Thus a product can be seen as a technical system (in case of a car), but not necessary as an energy specific technical system.

Through the product level it is possible to get insight in which products a technology diffuses. Think for instance of the diffusion of CHP through greenhouses and solar panels through residential buildings. Also one can detect technologies that are used in combination with each other; technologies that are often used in combination are likely to have well developed interfaces.

**Table 5 Example products per Application Area**

| **Application area** | | |
|---|---|---|
| **Transport** | **Industry** | **Buildings** |
| Car | Production Plant (Factory) | House (residential buildings) |
| Bus | Industrial Process | Office (commercial buildings) |
| Truck | Greenhouse | Utility (utility buildings) |
| Ship | Data Centre | |
| | Refinery | |
| | Power Plant | |

### 5.1.3 Level 2: Components

The components level distinguishes different technologies within a product. Furthermore components can be seen as technical systems within the energy domain that include a lot of internal interfaces and have limited interfaces toward the outside world. It is hard to give an unambiguous definition of the component level without giving examples, but it describes technologies in terms of solar panels, heat pumps, heat exchangers, ventilation systems and bio-boilers. These can be applied independent of products and application areas. On the component level modular configuration of a product can take place, but always a core component can be determined looking at internal interaction and core and peripheral elements. This level will be used as the base level for analysis in this research and will be directly related to the functional hierarchy.

### 5.1.4 Level 3: Sub-Components

A component can be further decomposed into sub-components. Also here only examples can give a description of the way subcomponents are defined in this research. One should think of LED's, generators, motors, boilers, heat exchangers or heat pumps as subcomponents. Also one should notice that some of the examples occur both in the list of examples for components as subcomponents. This can be explained, since some technologies are just a component aimed at a specific task within the product. While in other configuration this technology is part of an assembly of multiple sub-components. This has to do with size and a difference between direct and indirect application of the technology. An example could be a heat exchanger in a ventilation system, whereas this heat exchanger could also be placed, independently, in a product on the component level.

This level will be used to distinguish the core form the side components in order to determine the exact part on which the innovation takes place. This is often context and project related information that cannot be generalized and needs to be studied for each individual case.

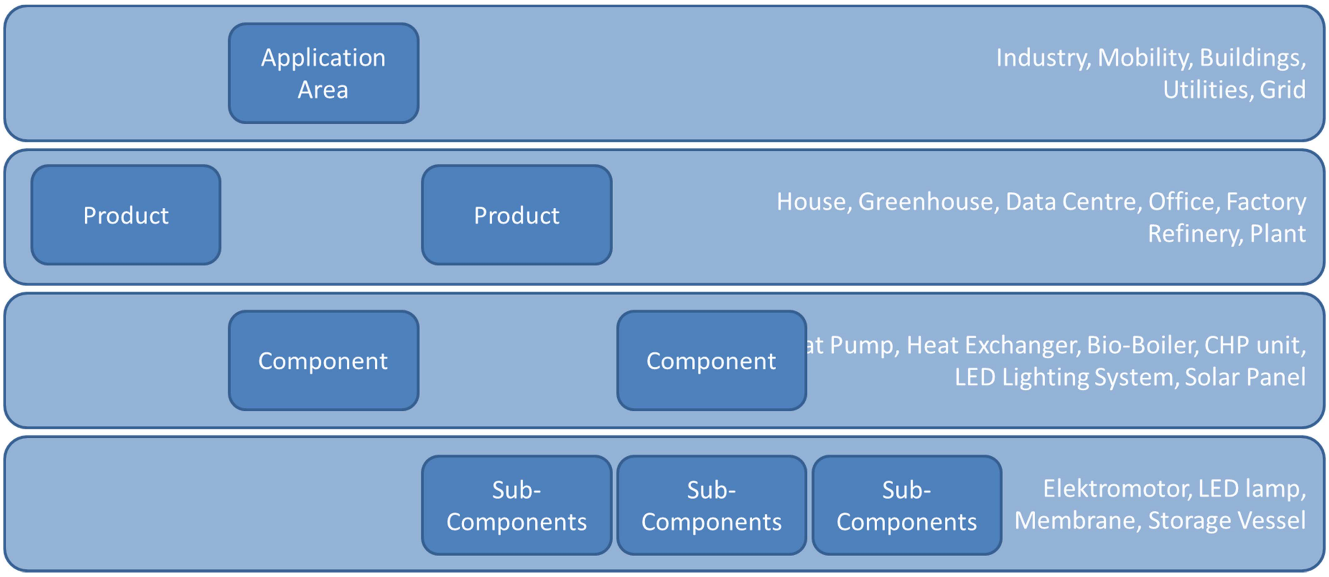


**Figure 10 Overview Physical Hierarchy and Examples**

## 5.2 Functional Hierarchy

Every technology can be seen a multifunctional artifact. A functional hierarchy decomposes and describes technologies by the societal function they fulfill or the purpose the technology has within a system. In a functional hierarchy the categories are determined by solution neutral definition of separate functions that the technology could fulfill. Also this can be done on multiple levels, similar to the physical hierarchy. Depending on the aggregation level, functions are described as system functions, main functions or sub-functions. In this paragraph the different levels are described in the way they are applied in this research.

**Table 6 Functional Hierarchy Definitions**

| Aggregation Level | Name | Definition |
|---|---|---|
| **0** | Policy goals | Overarching functional goal of energy technologies |
| **1** | System Functions | Categorization in production, conversion, distribution or storage systems |
| **2** | Main Functions | Categorization in energy related societal functions within functional system. |
| **3** | Sub-Functions | Can be used to determine core function of a technology on the main function level. |

### 5.2.1 Level 0: Policy Goals

Functions and requirements are distinct from goals. Functions and requirements describe what a technology should do in a black and white fashion (a function or requirement is ether fulfilled or not). Goals describe improvements of current practices and give direction to it (more of function A, less of function B). The two are often intertwined as described in "*House of Quality*" literature (Hauser & Clausing, 1988). Customers or designers make choices and trade-offs when determining the relative importance of a function and to what extent it should be fulfilled. Figure 11 Relation of Policy Goals to Functional Systems displays the relation between energy policy goals and energy technology functions. In this research it provides a high aggregation level categorization of technologies, which is easily translatable using figure 2. These goals are related to system functions in the next hierarchical level: the system function level.

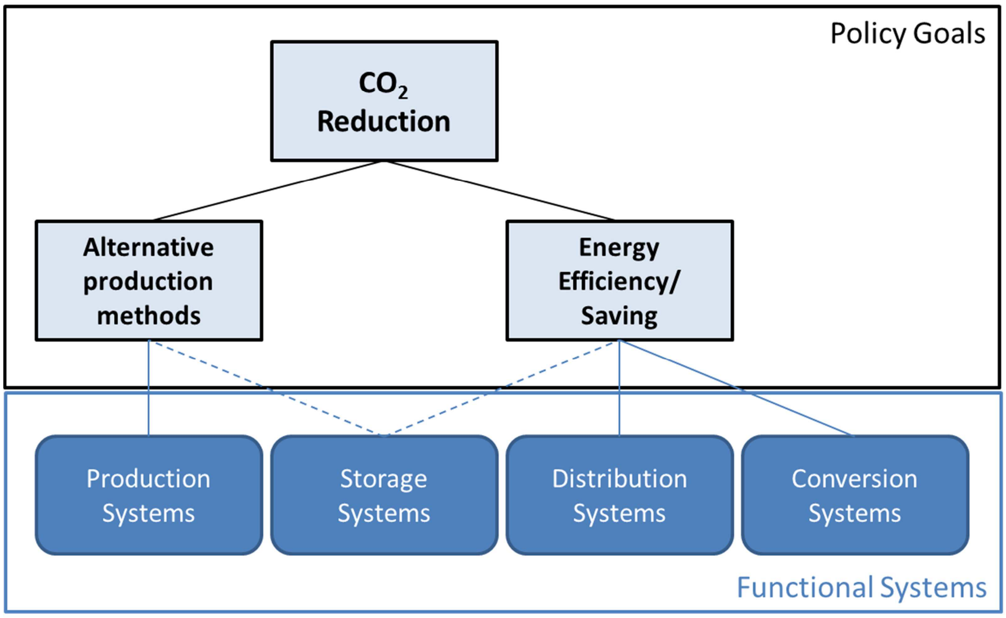


**Figure 11 Relation of Policy Goals to Functional Systems**

### 5.2.2 Level 1: System Functions

The system function level distinguishes four types of functional energy systems: production, storage, distribution, conversion. Within production systems technologies are categorized that convert natural resources into applicable and transportable energy carriers (heat, electricity, gas and others). Conversion systems describe technologies that are meant to use energy carriers for a societal function. Distribution systems and related technologies aim at the transport of energy carriers over larger distances between facilities and storage systems aim to store energy carriers in order to release them at a later point in time. An overview can be found in Figure 12 System Functions.

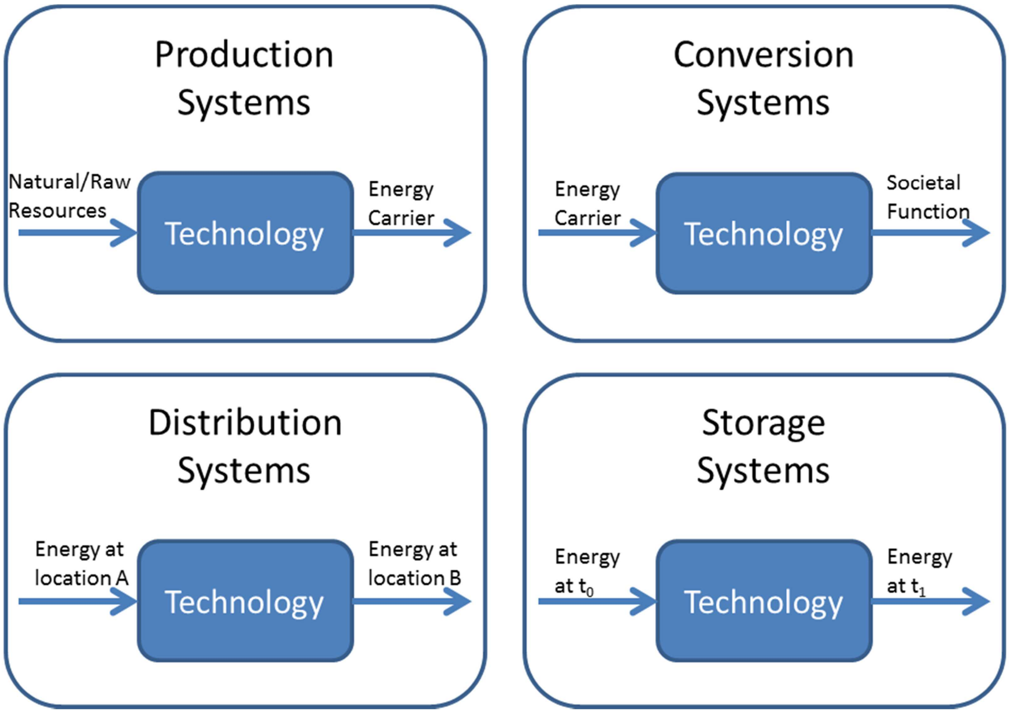


**Figure 12 System Functions**

The system function level can be used as a high level aggregation of technologies on their function. It also allows translation from policy goals to functional application (as described in the previous paragraph). Hybrid combinations of two system functions can occur. These will not form a separate category in the functional hierarchy (think of combined production/conversion systems or production/distribution systems), but the separate technologies of these systems will be further categorized on the main function level.

### 5.2.3 Level 2: Main Functions

The main functions level requires a different functional decomposition for energy production, conversion and storage technologies. All functions not related to energy are excluded from this decomposition.

For production systems the functional requirements are split up on terms of raw input. It is chosen to look at input because overlap occurs between functions when differentiating on outputs like heat, gas and electricity. Categories are determined on basis of the IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics (IEA, 2011) which distinguishes all means of energy production.

For conversion systems functions are decomposed on societal application or the societal aim the energy is used for. Within the IEA (International Energy Agency) guide there is not a specific overview of all societal functions of energy, but a lot of effort has already done here in the categorization of the Energy Investment Deduction (EIA). Therefor their functional categorization has been applied to a large extent.

Storage technologies distinguish by storing hydrogen, fuels, heat or electricity. These functions also depend on the IEA guide. Also allowing storage as being a hybrid between conversion and production will cause trouble at this level since it can be an intermediate energy carrier between many electricity, gas and heat applications.

Within distribution systems two main functions have been identified. On the one hand this has been managing energy which embeds technologies that aim at computer simulated models or metering devices that allow grid operators to reduce energy losses in transmission. The other part includes the building of new connections of the physical grids, for instance the building of new pipelines, transmission lines or heat networks.

Technologies that fulfill multiple main functions will be categorized in a multiple categories that describe the main functionality of that technology. Similar to the system functional level the multiple functions of these technologies can be further distinguished on a lower physical and functional level if necessary.

**Table 7 Main Functions per System Function**

| **Main Functions** | | | | |
|---|---|---|---|---|
| **Production** | **Conversion** | | **Storage** | **Distribution** |
| Producing Fossil Fuels | Heating | Lighting | Storing Hydrogen | Managing Energy |
| Producing Bio- Energy | Cooling | Reusing Energy | Storing Fuels | Transporting Energy |
| Producing Solar Energy | Ventilating | Industrial Processing | Storing Electricity | |
| Producing Wind Energy | Isolating | Monitoring & Controlling | Storing Heat | |
| Producing Geothermal Energy | Driving | Efficient Mobility | | |
| Producing Ocean Energy | Drying | Energy Efficiency (general) | | |
| Producing Hydrogen Energy | | | | |
| Producing Waste Energy | | | | |

### 5.2.4 Level 3: Sub-functions

Within the main functions, that are determined in the previous level, one can find different sub-functions. Sub functions can be applied and optimized in order to come to innovation. Production systems can distinguish multiple sub-functions in order to convert their raw resources; think for instance of the combusting, gasifying or fermenting functions within the conversion of biomass to energy.

Within conversion systems the combination of technologies in the sub-functional level is a main driver for innovation. This integration of technologies provides means of energy efficiency and can be reached through smart interaction between core functions or adding additional side functions.

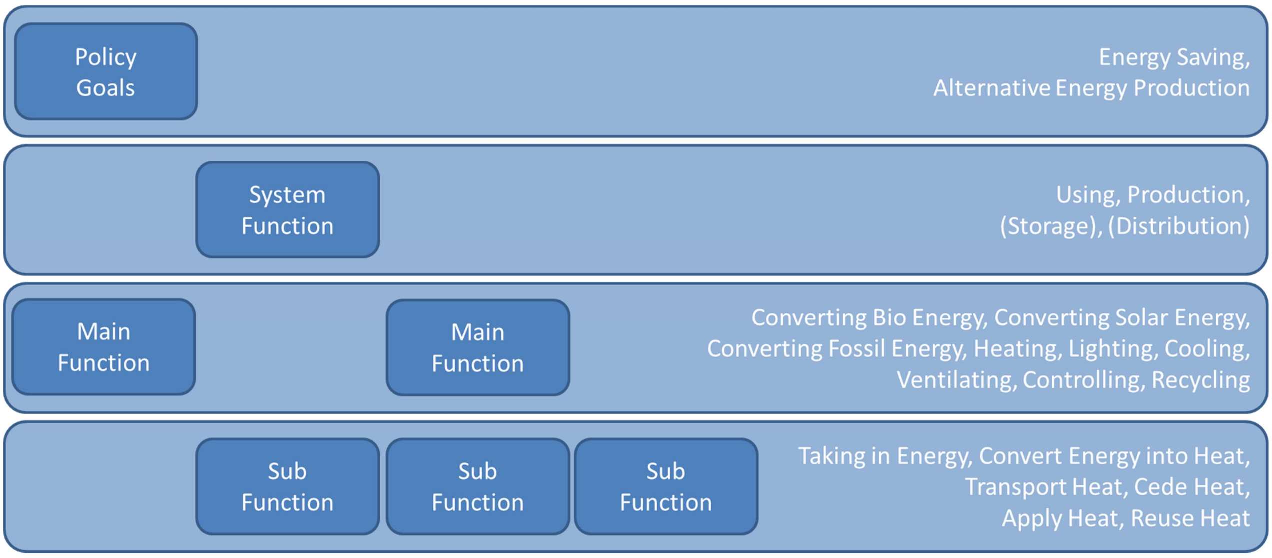


**Figure 13 Overview of Functional Hierarchy and Examples**

## 5.3 Relation between Physical and Functional Hierarchies

As mentioned before the physical and functional hierarchies do not exist independent of each other. In this paragraph the relationship between functional and corresponding physical levels is explained. By means of examples it is explained how complexities in the one domain should be solved by looking at the other domain or by further analysis within the same domain.

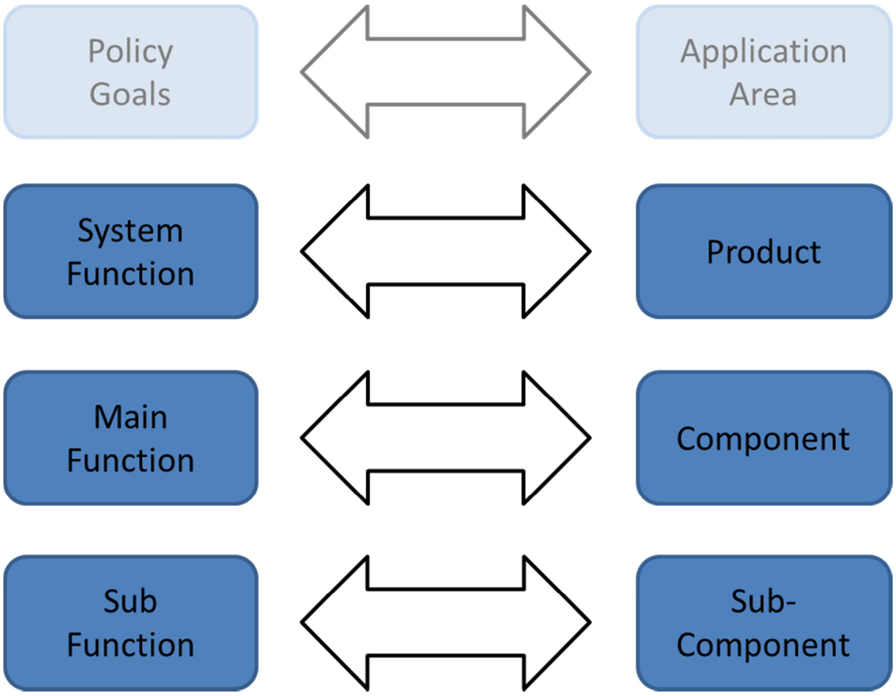


**Figure 14 Relation between Functional and Physical Hierarchy**

### 5.3.1 Relation between Policy Goals and Application Area

The relation between policy goals and application area is the most difficult to address. It requires a very specific boundary of what is meant by both terms, which is not discussed in this research. Only then a one-on-one relation can be addressed. For this reason the relation is more vaguely colored in Figure 14.

Despite from that, this level provides the upper boundary for functional decomposition in this research and helps to group lower level physical objects. Especially for the conversion-side, the grouping of technologies by application area shows large commonalities with the categorization used by the International Energy Agency (IEA, 2011). Also as technologies evolve from the products evolve from product to multiproduct purposes (think of energy efficient housing districts or communities), monitoring on the application area level could become valuable. At this level the relation to policy goals, like $CO_2$ reduction, becomes more concrete since it will be the only commonality between all technologies applied in such a district.

### 5.3.2 Relation between System Functions and Products

The product level should, ideally (in a single functional world), relate to the system function of the functional hierarchy. It distinguished in production, distribution, storage and conversion-systems. For some products, this categorization can be made directly; think of any form of power plant which is directly related to production. For others, like energy neutral houses or greenhouses, it might not be directly possible to functionally categorize the product; this is where combinations of two or more functional categories emerge.

One can detect multifunctional technologies that are used in combination with each other. For instance an energy neutral house, which includes small production for internal conversion, is a conversion - and a production system at this level. This distinction is better possible on a more detailed level, looking at separate components.

Furthermore technologies can be similar in system function but distinct in product and vice versa. An example is that both houses, industrial buildings and commercial buildings perform a conversion function, still they use different technologies. Also considering the production side of these products, and industrial building would need production on a much larger scale and therefor has fewer benefits from small scale production units like photovoltaic solar cells.

### 5.3.3 Relation between Main Functions and Components

On the component & main functional level an unambiguous system function of the technology can be determined. This system function will be based on the specific aim of the technology in the context in which it is embedded. For some components the system function is still unclear. Think for instance a CHP-unit that heats a product (in the definition of paragraph 4.2.2) and sells electricity to the grid. This can be seen as a conversion system converting gas into heat, or a production system converting gas into electricity. In the context that the heating is the dominating function it can be categorized as a conversion system, while electricity production as a dominating function will result in categorization under production systems.

Nevertheless multifunctional components can still be classified although one would need a rule how to deal with these kinds of technologies. This can either be in extra categories dealing with so called hybrids (method A) or multiple categories at the same time on a lower hierarchical level (method B). The advantage of extra categories is that it ensures the unambiguity between categories, whereas placing the same technologies in multiple categories will cause ambiguity. The advantage of multiple categories is that it maps a higher amount of information. It allows a technology to be used in two different contexts instead of one. Still these issues should be examined for all technologies separately, since in some cases method A is better, while in others method B is preferable. I will further elaborate this issue in Chapter 6 Application .

### 5.3.4 Relation between Sub-Functions and Sub-Components

On the level of subcomponents one should be able to specify a main function for every technology. This should be done by describing the sub-functions of a hybrid components and determine the dominant function of the technology. Still this is a difficult practice which is hard to do objectively along the same procedure. A procedure like this is mostly necessary if one wants to distinguish the actual innovation on the sub-functional/sub-component level. This for instance can be the addition of a new sub-system, which has not been previously applied in this specific main function (think of heat exchangers in ventilation systems).

# 6. Application Procedure

This paragraph describes the application procedure for technology classification. This results in a six step procedure. Furthermore important aspects as the core components and multifunctionality are discussed as being difficult. Finally target classes are once more mentioned.

## 6.1 Classifying Technology Components in Project

Most technologies classified in this thesis are embedded in projects. This means that the context of the isolated technology is broader than the technology only. Most projects embed more than one technology component. This requires the determination of core components. Also multifunctionality is an issue that can be encountered often.

### 6.1.1 Determining the Core Components:

The determination of core components and is also recognized as a problem by Murmann & Frenken (2006), who describe core and peripheral components when studying dominant designs of technologies. In this research the core needs to be determined by looking at the innovative part of the project, for instance the new heat pump system of a house is innovative, but the isolation used is standard.

Sometimes determining the core requires a broader understanding of the use of physical and functional hierarchies. Think for instance of heat reuse in ventilation (7.3.2): the core is ventilation, with a subsystem that ensures heat reuse. Another example a project regarding smart grids (7.4.1): A monitor and control system mostly represents the core functionality while other components (or even products), represent subsystems that enable an energy management system to perform its functionality.

A more practical advice can be offered as well. A useful help for determining the core component can be found in looking at the original policy program (most often the case for TSE-projects) in which the project is embedded. This is for example how the smart grid example in the previous paragraph was determined; smart grids consider the application of energy management systems (EMS). This will allow one to distinguish between core and peripheral components and also allows determining the innovative part of the technology.

### 6.1.2 Dealing with Multifunctionality

Besides core components a second difficulty arises. CHP is an example of a real difficult practice when looking at the core component: it is equally capable of producing electricity or heat at the same time and the innovation lies in the combination of the two. In this thesis we call these multifunctional technologies.

Multifunctional technologies need further decomposition to be classified. Since it is a choice to limit the level of analysis for this thesis to two levels these technologies will be classified in multiple categories. It should be noted that this is very exceptional since the key of a good morphological structure does not allow redundancy. One can choose to categorize this kind of technology in multiple categories or in a separate category for hybrids. It is in the nature of technology to add sub functions within components and integrate already existing functions and subsystems (Arthur, 2009). Therefor the addition of hybrid categories will create a mess of endlessly extending functional categories if one remains in a limited amount of hierarchical levels. Next to that in the physical classification these technologies belong to one single physical class, therefor I will allow the fact that these technologies need to be assigned twice on the functional side.

## 6.2 Classification Steps

For every technology one should follow a standard formal procedure when classifying along the categories. This procedure is explained in this paragraph. Generally the procedure consists of the following steps:

1. Determine the physical level of the technology.
2. Assign product category (In case of level 1 Technology)
3. Decomposing the physical technology into component parts (In case of level 1 Technology)
4. Assign component category per component
5. Assign a main function to the components
6. Assign a system function to the components

This can be represented in the following figure:

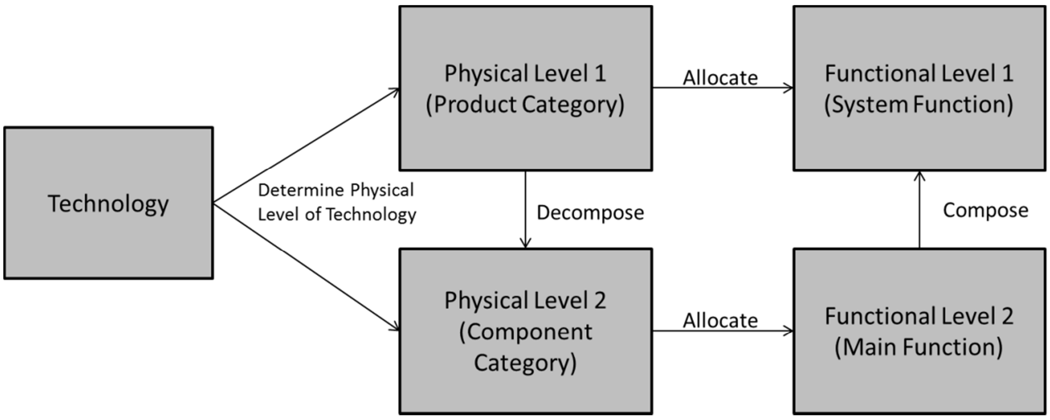


**Figure 15 Classification Steps**

When assigning all categories one requires understanding of the concepts of functional and physical technologies:

For the physical decomposition, determining the product and component category, one should ask the question "*in which [product/component] is the technology embedded*". This question will always be asked on one hierarchical level lower than at which the category is assigned: product category will be determined on the component level, component category will be determined on the sub-component level. Subsequently a component inherits the product category of the product it is physically embedded in.

For the functional, decomposition the system and main function category, one should ask the question *"what is this technology purposed for"*. It is best to determine the function per component, before determining it for a product of as a whole. After that, products can easily be addressed on system functions; still this requires determination of core components, as will be elaborated on in the next section.

## 6.3 Classes for Registration

Once the classification procedure has been executed, for every technology (both EIA and TSE) the following information should be available:

1. Technology Code
2. Name
3. Product Category
4. Component Category
5. System Function Category
6. Main Function Category

These categories will describe two functional and two physical levels of the technology. For some technologies it is possible to go one aggregation level deeper or higher. This will not change the procedure as described in section 6.. In theory we could endlessly decompose in both physical as the functional world, as proposed in section 4.3 Conceptual Classification Model.

For this research only these four categories are compared. The reason for this is that on these two levels it is possible to categorize all EIA-technologies. For EIA technologies, a large difference exists on the level of detail in which they are described. I will stress that this is a deliberate choice: If necessary this analysis can be extended in the future to lower or higher aggregation levels using the same conceptual basis. A proof of principle for further deepening or going to a higher aggregation level will be given in section 7.3 Complicated Cases and 7.5 Types of Complicated Cases.

# 7. Application of Classification Method

In this chapter I will apply the classification method. First of all prove of principle will be given by doing a couple of simple examples in which the classification system and application procedure are applied. Secondly I distinguish between standard cases and complicated cases. For each complicated case I will address the main difficulty of that specific case.

## 7.1 Recap of Key Complexities

In the problem statement of this research three key issues were stated as being essential complexities that this model should deal with. Within this paragraph I once more describe the complexities and I will refer to the next paragraphs in which examples are given that verify the ability of the classification system to deal with these complexities.

First of all, I stated that a categorization or classification is necessary for comparison of technologies. Within section 7.2 the classification of both EIA and TSE projects is demonstrated by some “easy” examples. I choose a number of examples from different fields and practices to demonstrate that the method is not only applicable at one type of technology only.

Secondly within section 7.3, more difficult cases are demonstrated. Within these examples there is the necessity to understand the difference between functional and physical technologies (7.3.1) and the necessity to understand technological hierarchies to differentiate between technological systems and sub-systems (7.3.2). A third example (7.3.3) will show the ability of the method to classify innovative technologies that are not fully matured yet.

## 7.2 Standard Projects

Within this section a number of standard technologies and projects will be discussed. These projects will form a demonstration for the application of the procedure as specified in chapter 6. Step by step the technology will be broken down and classified in product and component parts, together with corresponding functional categories.

### 7.2.1 LED-Lighting System for Horticulture
(EIA220503)

As a first example we will look at EIA220503, which is the EIA-reference code for a LED-Lighting System for Horticulture. For this technology it is specified what the technology is and in what kind of context it is applied. The application in horticulture means the techology diffuses through greenhouses, which can be identified as the product category. The lighting system itself is a component; it can be applied in multiple greenhouses on different locations.

Working from the physical realisation of the technology (LED-Lighting System in a Greenhouse), one can start determining the function the physical technologies fulfill in a conceptual way. This means they will be classified within a category of possible substitutes. The LED-Lighting System will be classified within the main functional category lighting, part of the system category conversion. Together with the physical classification categories, one has now classified the specific physical realisation of the technology and its functional conceptualisation. This allows to find functional alternatives and variations in technology, also one can identify dominant practices within a certain product category (for example, greenhouses use LED systems where buildings are not supported in the replacement of old fashioned lighting systems).

| |
|---|
| 1. <u>Determining the physical level of the technology.</u><br>This technology is a component (according to the Object Model for Innovation definitions), and therefore assigned at physical level 2.<br>2. <u>Assign product category</u><br>*Product Category:* Greenhouse<br>3. <u>Decomposing the physical technology into component parts (In case of level 1 Technology)</u><br>The project is a component itself<br>4. <u>Assign component category</u><br>*Component Category 1:* Lighting System<br>5. <u>Assign a main function to the components</u><br>*Main Function of Component 1:* Lighting<br>6. <u>Assign a system function to the components</u><br>*System Function of Component:* Conversion |

### 7.2.2 Innovative Renovation with PVT
(DEMO01018)

This EOS project (predecessor of TSE) aims for the implementation of photovoltaic thermal (PVT) systems in 154 houses in Alkmaar. The PVT system, in this case, diffuses through houses. Thus the project can be decomposed into houses with PVT systems as a component. This corresponds to the product category residential building and the component category PVT.

For the simplicity of this demonstration case, we will assume that the function of the technology is a converting solar energy that does not directly apply the heat through a heating device. Therefor the system category will be production. On a lower level on could distinguish between the two (to be elaborated on in section 7.3.2 Heat Recovery Ventilation).

| |
|---|
| 1. <u>Determining the physical level of the technology.</u><br>This project is a demonstration of a component in a product (according to the Object Model for Innovation definitions), these are assigned at physical level 1.<br>2. <u>Assign product category</u><br>*Product Category:* Residential Building<br>3. <u>Decomposing the physical technology into component parts (In case of level 1 Technology)</u><br>The component applied in the houses is a PVT system combining photovoltaic and thermal application of solar energy<br>4. <u>Assign component category</u><br>*Component Category 1:* PVT<br>5. <u>Assign a main function to the components</u><br>*Main Function of Component 1: Converting Solar Energy*<br>6. <u>Assign a system function to the components</u><br>*System Function of Component: Production* |

### 7.2.3 Adsorption Heat Pump
This example includes a project from a Topsector Energy Project. Project TEGB113010 includes a development project in which an adsorption heat pump is developed that can be placed in all sorts of buildings. This can directly be translated to physical component and product categories (see Table 8 Overview of Standard Classification Projects).

Following from this system and main functional categories can be assigned. The heat pump fulfills the function of heating. Furthermore heating is part of the system function conversion. Therefor the project gets classified as a heating and conversion project in the functional classification.

1. Determining the physical level of the technology.

This project is the development of a component (according to the Object Model for Innovation definitions) these are assigned at physical level 2.

2. Assign product category

*Product Category:* Building (unspecified)

3. Decomposing the physical technology into component parts (In case of level 1 Technology)

The component applied in this project is an Adsorption Heat Pump

4. Assign component category

*Component Category 1:* Heat Pump

5. Assign a main function to the components

*Main Function of Component 1: Heating*

6. Assign a system function to the components

*System Function of Component: Conversion*

**Table 8 Overview of Standard Classification Projects**

| Project number | Subject | Product Category | Component Category | System Function Category | Main Function Category |
|---|---|---|---|---|---|
| EIA220503 | LED-Lighting System for Horticulture | Greenhouse | Lighting System | Conversion | Lighting |
| DEMO01018 | Innovative renovation with PVT | Residential Building | PVT-System | Production | Producing Solar Energy |
| TEGB113010 | Adsorption Heat Pump for sustainable heating of existing buildings | Building (unspecified) | Heat Pump | Conversion | Heating |

## 7.3 Complicated Cases

### 7.3.1 Heat Pump, Boiler and Heating Technologies
(DEMO01014, EIA211103 & EIA221103)

Within the context of these projects the technology (a heat pump) is used to fulfill the function heating. One could classify this project as a heat pump project only, but functionally it is similar to, for instance, a boiler: both are a proven technology for the function heating. This makes this heat pump project an example of where an extra hierarchical level is necessary for grouping. Further distinction between boilers and heat pumps could not be made in the functional level but requires the physical classification. The functional category, in this case, provides an overview of possibilities. In the same time both are substitute of each other, where, in some occasions a new boiler is applied (for instance combined with biomass fuel) and in other situations a heat pump is applied. Table 9 Overview Classifications of section 7.3.1 shows the final outcome of the classification; also referring EIA technologies for heat pumps are classified here.

Procedure for DEMO01014, Trinitas College Heerhugowaard (heat pump project):

1. <u>Determining the physical level of the technology.</u>

This project is a demonstration of a product (according to the Object Model for Innovation definitions), these are assigned at physical level 1.

2. <u>Assign product category</u>

*Product category: school.* In the case of project DEMO01014 a heat pump is applied in a school in Heerhugowaard

3. <u>Decomposing the physical technology into component parts.</u>

The component applied in this product is a heat pump (core technology). Next to that the following also a High Efficiency Peak Boiler and a Ventilator with Heat Recovery are applied.

4. <u>Assign component category</u>

*Component Category: Heat pump*
*Component Category 2: Boiler*
*Component Category 3:* Ventilator → to be discussed in next paragraph.

5. <u>Assign a main function to the components</u>

*Main Function of Component: Heating*. For project DEMO01014 two heating components will be distinguished: the heat pump and high efficiency peak boiler.

6. <u>Assign a system function to the components</u>

*System Function of Component:* Conversion*.* Also the system function of the components is conversion.

### 7.3.2 Heat Recovery Ventilation

Examples related to this paragraph: DEMO01014 & EIA210801.

A number of the categorized projects describe a system for heat recovery in a ventilation system. These kinds of technologies can be categorized in multiple ways. When someone is looking at the *innovative* part of the technology this technology would functionally describe a heat recovery system. When looking at the *core component* of the technology (like described in 6.) it will become clear the core technology is a ventilation system from which the functionality is extended by a heat recovery (sub)system.

For EIA210801 & the Ventilator component of DEMO01014:

1. <u>Determining the physical level of the technology.</u>

This technology describes a component (according to the Object Model for Innovation definitions), these are assigned at physical level 2.

2. <u>Assign product category</u>

*Product Category:* Building. Within the EIA categorization EIA210801 is categorized under buildings

3. <u>Decomposing the physical technology into component parts (In case of level 1 Technology)</u>

Not applicable (physical level 1 is missing)

4. <u>Assign component category</u>

*Component Category:* Ventilator (with Heat Recovery)

5. <u>Assign a main function to the components</u>

*Main Function of Component: Ventilating*. For technology EIA210801 main function is ventilating, not the heat recovery aspect, this is a “subcomponent/function.

6. <u>Assign a system function to the components</u>

*System Function of Component:* Conversion*.* The system function of the component is conversion.

### 7.3.3 SOLAR POWER, HEATING AND COOLING DEVICE: TRI-STAR CONCEPT

Examples related to this paragraph: NEOH03011

This project describes a project that researches the feasibility of the Tri-Star concept for converting solar power. It is an example of a project that does not aim to result in a physical component or product and needs more innovation and development steps beyond the project in order to come to a physical realization of the concept. Next to this, this example project also deals with function integration on a sub-functional level (regarding to the direct application of solar power, heating and cooling within one integrated device). From that perspective it is also a complicated case as described in section 7.3.2.

1. Determining the physical level of the technology.

Research and development project with no physical level

2. Assign product category

*Product Category:* -

3. Decomposing the physical technology into component parts (In case of level 1 Technology)

The components applied in this project are: none

4. Assign component category

*Component Category 1:* none

5. Assign a main function to the components

*Main Function of Component 1:* -

6. Assign a system function to the components

*System Function of Component:* -

**Table 9 Overview Classifications of section 7.3.1, 7.3.2 and 7.3.3**

| Project number | Subject | Product Category | Component Category | System Function Category | Main Function Category |
|---|---|---|---|---|---|
| **DEMO01014** | Trinitas College Heerhugowaard | School | Heat Pump | Conversion | Heating |
| **DEMO01014** | Trinitas College Heerhugowaard | School | Boiler | Conversion | Heating |
| **DEMO01014** | Trinitas College Heerhugowaard | School | Ventilator | Conversion | Ventilating |
| **EIA211103** | Heat Pump | Building (unspecified) | Heat Pump | Conversion | Heating |
| **EIA221103** | Heat Pump | Industrial Process (unspecified) | Heat Pump | Conversion | Heating |
| **EIA210801** | Cold and Heat Recovery from Ventilation Air | Building (unspecified) | Ventilator | Conversion | Ventilating |
| **NEOH03011** | Tri-Star | - | - | Production | Producing Solar Energy |

## 7.4 OTHER COMPLICATED EXAMPLES

### 7.4.1 SMART GRID PROJECTS

Example related to this paragraph: IPINS01002

Smart Grid projects aim to integrate a lot of functionalities in the context of a single project. This often includes technologies from all system functions (production, distribution, storage and conversion) and also a lot of relevant innovative components. Smart Grid projects therefor require more decomposition than most other projects.

A second difficulty of these integration projects is that they include technologies that are already 'proven' to a large extent. This makes that these technologies are described by the name that the company that built them gave to the technology.

1. Determining the physical level of the technology.

This project is a demonstration of a product (according to the Object Model for Innovation definitions), these are assigned at physical level 1.

2. Assign product category

*Product Category:* Houses

3. Decomposing the physical technology into component parts (In case of level 1 Technology)

The components applied in this project are: Energy Management System, Photovoltaic Installation, Wind park, Biogas Installation.

4. Assign component category

*Component Category 1: Energy Management System*
*Component Category 2: Photovoltaic Installation*
*Component Category 3: Wind Turbine*
*Component Category 4: Biogas Installation*
*Component Category 5: Smart Appliances*

5. Assign a main function to the components

*Main Function of Component 1:* Managing Energy
*Main Function of Component 2: Converting Solar Energy*
*Main Function of Component 3: Converting Wind Energy*
*Main Function of Component 4: Converting Bio Energy*
*Main Function of Component 5: Monitoring and Controlling*

6. Assign a system function to the components

*System Function of Component 1: Distribution*
*System Function of Component 2: Production*
*System Function of Component 3: Production*
*System Function of Component 4: Production*
*System Function of Component 5: Conversion*

**Table 10 IPINS01002 Classification**

| Project number | Subject | Product Category | Component Category | System Function Category | Main Function Category |
|---|---|---|---|---|---|
| IPINS01002 | Houses municipality of Zeewolde | Residential Building | Energy Management System | Distribution | Managing Energy |
| IPINS01002 | Houses municipality of Zeewolde | Residential Building | Photovoltaic Installation | Production | Producing Solar Energy |
| IPINS01002 | Houses municipality of Zeewolde | Residential Building | Wind Turbine | Production | Producing Wind Energy |
| IPINS01002 | Houses municipality of Zeewolde | Residential Building | Biogas Installation | Production | Producing Bio Energy |
| IPINS01002 | Houses municipality of Zeewolde | Residential Building | Smart Appliances | Conversion | Monitoring and Controlling |

### 7.4.2 Generic Codes

(EIA310000, EIA410000, EIA320000, EIA420000, EIA340000, EIA440000, EIA450000)

Generic codes on the EIA list allow companies to apply for subsidy for technologies not directly described by the technologies specified on the list. Also a bundle of energy saving measures can be subsidized under this code.

Within the EIA list the different codes refer to different application areas, therefor they can be defined on physical and functional level 1 only, where the physical classification often is a vague description of a product on which the technology applies. In the table below I classified all Generic Codes using the same procedure as in previous paragraph.

**Table 11 Classification of Generic Codes**

| Project number | Subject | Product Category | Component Category | System Function Category | Main Function Category |
|---|---|---|---|---|---|
| EIA210000 | Improve Energy Label | Building | - | Conversion | - |
| EIA310000 | Energy Saving Existing Building | Building | - | Conversion | - |
| EIA410000 | Energy Saving New Building | Building | - | Conversion | - |
| EIA320000 | Energy Saving Existing Industrial Processes | Industrial Processes | - | Conversion | - |
| EIA420000 | Energy Saving New Industrial Processes | Industrial Processes | - | Conversion | - |
| EIA340000 | Energy Saving Existing Transport | Transport | - | Conversion | - |
| EIA440000 | Energy Saving New Transport | Transport | - | Conversion | - |
| EIA450000 | Use of Renewable Energy | Energy | - | Production | - |

## 7.5 Types of Complicated Cases and their Solution

In the previous paragraphs I demonstrated cases that were hard to classify or that required a conceptual understanding of the classification system as is central in this thesis. In this paragraph I will classify these complicated cases by type. These cases can be found in Table 12 Types of complicated cases

**Table 12 Types of complicated cases**

| # | Type of Complication | Paragraph | Description | Solution |
|---|---|---|---|---|
| **1.** | **Functional Substitutes** | 7.3.1 | Clear difference between physical and functional categories on component level. | Test and train conceptual understanding of users of the difference between functional and physical classification |
| **2.** | **Sub-Systems** | 7.3.2 | Innovation takes place by addition of a subsystem on the sub component level | 1. Test and train conceptual understanding of users and integrate the knowledge of specialists.<br>2. Allow extra layers for classification |
| **3.** | **Pre-Component Phase** | 7.3.3 | Missing realization in the physical domain due to the fact that the technology is under development. | Describe functionality only |
| **4.** | **Function Integration** | 7.4.1 | Multiple system functions within projects/technologies therefor a high amount of components and a long list of decomposed items. | Classify by components only and link components to the parent project/technology. (Requires to bound decomposition to innovative technologies only) |
| **5.** | **General Technologies** | 7.4.2 | For EIA some technologies are defined in a general way, this means that no exact components are defined in a product. | Leave fields open or when information is available: classify case by case. |

In general one can distinguish between theoretical difficulties (1-3) and practical difficulties (4 and 5. Theoretical difficulties get back to the anticipated problems in the problem statement of this research. Practical difficulties were only encountered during the classification process and have no anticipated theoretic basis.

Regarding difficulty one, functional classification was chosen as a solution for the categorization of technologies. This comes with the drawback that in some cases information regarding the physical technology is lost. The addition of a physical classification solves this imperfection. In 7.3.1 the mentioned technologies are functional similar and physical distinct. Further difficulty of this choice regards the understanding of users; users need to be aware of the necessity of both a functional and physical classification. This is not clear at once since it looks like double work for many technologies. “Why classifying one technology both as a ventilation system (physical) and a system aimed at ventilation (functional)?” is a question that is very likely to be asked and not relevant for every technology. For the examples regarding heating technologies this distinction is necessary.

Regarding difficulty two, the level of analysis has been very hard to define within this classification system. One could continue decomposition to a very extensive and deep level, where ever more specialized knowledge is necessary to make a further distinction between functionally similar technologies. Where specialists see the addition of a functional subsystem, a general perspective just sees a technology with a better performance. For the goal of effect monitoring these two perspectives form a trade-off. Regarding this it is chosen to classify only two physical and functional levels. But the methodology used (section 4.3 Conceptual Classification Model) allows more detailed registration. In this way the heat recovery subsystem of the example in 7.3.2 can be registered in future practices. Collaboration with specialist in these cases might be a necessity.

Difficulty three gets back to the innovative character of some projects, which have no realization in the physical domain yet. These projects can be classified using functional classification only. Difficulty four needs to be solved on a case to case basis. They require the judgment of the user to determine the innovative character of technologies to prevent from having an endless list of components. This is context dependent. Section 6. also discusses this difficulty.

Difficulty five is one that will not occur in many future projects and that is very specific regarding some EIA technology codes. When it occurs it should be classified as a system function and product category only technology.

For these difficulties it is important that users learn how to deal with these cases in a structural and conceptual way. In this way one can assure the consistency (and thus quality) of the classification system. User understanding of the difference between functional and physical categories is critical in the application of this classification system.

# 8. RESULTS OF ALIGNMENT AND ANALYSIS

The original goal of this study was to compare EIA and TSE technologies in order to analyze their alignment. After applying the conceptual model (Chapter 4 and 5) according to the classification procedure (Chapter 6), technologies in the EIA-policy, TSE-policy and predecessors of the TSE can be compared. Chapter 7 elaborated on the application of the procedure by reporting on the standard cases and complicated cases. This chapter will report the results of comparison for alignment and an analysis of these results looking for explanation of misalignment within technology classes.

## 8.1 DATA, DEFINITIONS AND METHOD FOR ANALYSIS

In this chapter the results of comparison are presented. In order to be able to interpret the results it is necessary to know what is presented in terms of data (method) and what the recurring words regarding policy instruments in the table mean and the method that is used to classify categories as aligned or not aligned.

### 8.1.1 METHOD: COUNTING TECHNOLOGIES

Within this chapter technologies are reported by counting the number of cases per category. One should remind that technologies are seen separate from projects; projects can contain multiple technological components after physical and functional decomposition. Therefor projects can be counted two, three or more times within the analysis.

The relative low amount in Table 13 of EIA-project can be explained since it represents the technologies on the EIA-list only; these are labelled by the so called EIA-code. The used database does not include information about the number of projects applied per EIA-code. For the analysis of alignment (Further defined in paragraph 8.1.3), this is not relevant as long as the category shows no alignment.

### 8.1.2 POLICY INSTRUMENTS, TIMEFRAME AND INNOVATION PHASES

As mentioned before projects are classified functionally and physically. Functional and physical categories are used to make a more detailed comparison of technologies in policy instrument. Within the categories a distinction is made between EIA-technologies, TSE-technologies and Pre-TSE-technologies.

As can be read in the thesis introduction, EIA focusses mostly on the deployment and diffusion phase, where TSE and Pre-TSE focus on Research, Development and Demonstration. Also it is important to note that there is a large difference in number of projects per policy instrument and the timeframe which is taken into account for this analysis. The lower amount of TSE projects compared to Pre-TSE can be explained by the shorter time frame.

**Table 13 Information per Policy Instrument**

| Short | Policy instrument(s) | Timeframe | Number of Projects | Innovation Phase |
|---|---|---|---|---|
| **EIA** | Energy Investment Deduction | 2011-2014 | 179 | Deployment and Diffusion |
| **TSE** | Top Sector Energy Policy | 2011-2013 | 431 | Research, Development and Demonstration |
| **Pre TSE** | Energy Research Agenda (EOS)<br>Innovation Agenda Energy (IAE) | 2005-2011 | 2408 | Research, Development and Demonstration |

### 8.1.3 Reviewing Alignment

The number of projects is used as an indicator to measure alignment. Since there is no predefined scale for alignment and no statistical method is used to measure the alignment of cases a different approach is used to review alignment within categories. It should be clear that 0 cases of either TSE or EIA technologies within a category can be explained as “no alignment”. Secondly it is hard to distinguish between low and high alignment: low alignment includes the categories with <5 cases of either EIA or TSE, high alignment includes the categories with >= 5 cases. An overview can be found in Table 14 Types of Alignment.

**Table 14 Types of Alignment**

| Type of Alignment | Explanation |
|---|---|
| **No Alignment** | 0 cases of either TSE or EIA technologies within category |
| **Low Alignment** | <5 cases of TSE or EIA technologies |
| **High Alignment** | >=5 cases of TSE or EIA technologies |

It should be clear that the numbers as chosen in this division could be altered. They are not funded by scientific sources, but the aim is to make a distinction between highly aligned groups and low aligned groups of technologies. The most important are the technology groups that show no alignment at all.

## 8.2 System Function Categories

The highest aggregation level of the classification on the functional side is called the system function. System functions are described elaborately in section 5.2.2. From this section can be derived that there is a functional distinction between production, conversion, distribution and storage systems. Energy technologies belong to either one of the before mentioned system functions. Based on the system functions a first level analysis of EIA and TSE alignment can be made. This can be found in Table 15 Alignment of technologies on the System Functional level:

**Table 15 Alignment of technologies on the System Functional level**

| **Count of Dossier** | **Column Labels** | | | |
|---|---|---|---|---|
| **Row Labels** | **EIA** | **TSE** | **Pre TSE** | **Grand Total** |
| Production | 27 | 325 | 1045 | 1397 |
| Conversion | 146 | 98 | 691 | 935 |
| Distribution | 1 | 33 | 105 | 139 |
| Storage | 2 | 23 | 81 | 106 |
| **Grand Total** | **176** | **479** | **1922** | **2577** |

As can be derived from Table 14 Types of Alignment and Table 15 one can distinguish a “low alignment” in distribution and storage technologies. Especially EIA has a low amount of technologies that belong to these categories, but also a large difference in amounts of TSE and Pre-TSE occurs. These numbers can partially be explained by looking at the total number of projects in the different policies.

For production and conversion systems one can see that on the system function level there are a lot of technologies present of the both policies. On this level they can be considered aligned. In order to get more specific information on the alignment of these categories it is necessary to go one aggregation level deeper and look at the main functions of these technologies. This will be done in the next section.

## 8.3 Main Function Categories

As described in the previous paragraph the system function level does not give a fully detailed overview of alignment, since misalignment can be explained mostly by total number of cases. The main functional level will help to add some more detail to the analysis. In here we hope to spot some categories with no alignment within the system functional categories. As an example case conversion technologies will be analyzed more in depth in the following paragraphs. Based on the empirical results (8.3.1), analysis is used to get a better understanding of these results and find explanations for possible misalignment (8.3.2). In light of these explanation also "Pre-TSE" technologies are introduced in the comparison (8.3.3)

### 8.3.1 Results of Main Functional Categories

In table 17 one can find the results for main functions. Additional to the mapping, a Chi-Square test was performed in order to make sure that misalignment was not due to a statistical error.

**Table 16 Results main functional level**

| Count of Dossier | Column Labels | | | | Chi Square Test |
|---|---|---|---|---|---|
| Row Labels | EIA | TSE | Pre TSE | Grand Total | P value TSE & EIA |
| **Production** | **27** | **325** | **1045** | **1397** | 1.80E-07* |
| Producing Bio Energy | 14 | 127 | 452 | 593 | |
| Producing Energy | 2 | 2 | 0 | 4 | |
| Producing Geothermal Energy | 1 | 0 | 37 | 38 | |
| Producing Hydro Energy | 1 | 0 | 0 | 1 | |
| Producing Hydrogen Energy | 0 | 4 | 39 | 43 | |
| Producing Ocean Energy | 0 | 0 | 10 | 10 | |
| Producing Solar Energy | 4 | 90 | 224 | 318 | |
| Producing Waste Energy | 1 | 0 | 1 | 2 | |
| Producing Wind Energy | 1 | 33 | 121 | 155 | |
| Producing Fossil Energy | 3 | 69 | 161 | 233 | |
| **Conversion** | **146** | **98** | **691** | **935** | 7.52E-27* |
| Heating | 20 | 11 | 167 | 198 | |
| Cooling | 19 | 0 | 15 | 34 | |
| Ventilating | 13 | 9 | 58 | 80 | |
| Isolating | 11 | 0 | 116 | 127 | |
| Driving | 13 | 34 | 103 | 150 | |
| Drying | 14 | 0 | 16 | 30 | |
| Lighting | 6 | 0 | 26 | 32 | |
| Reusing Energy | 20 | 0 | 79 | 99 | |
| Industrial Processing | 6 | 9 | 73 | 88 | |
| Monitoring & Controlling | 17 | 35 | 32 | 84 | |
| Efficient Mobility | 7 | 0 | 6 | 13 | |
| **Distribution** | **1** | **33** | **105** | **139** | 0.0202* |
| Managing Energy | 0 | 27 | 47 | 74 | |
| Transporting Energy | 1 | 6 | 58 | 65 | |
| **Storage** | **2** | **23** | **81** | **106** | 1.47E-67* |
| Storing Unspecified | 0 | 3 | 17 | 20 | |
| Storing Fuels | 0 | 0 | 2 | 2 | |
| Storing Heat | 1 | 4 | 27 | 32 | |
| Storing Hydrogen | 0 | 2 | 5 | 7 | |
| Storing Electricity | 1 | 14 | 30 | 45 | |
| **Grand Total** | **176** | **479** | **1922** | **2577** | |

*P Value of >0.05 tells us the numbers are statistically different.

### 8.3.2 Analysis of Results

The aim of this analysis is to point out which of the main functional categories, considering EIA and TSE, are aligned in terms of technologies. In section 8.1 we pointed out three grades of alignment. In this paragraph these three grades are applied at the categories presented in table 16:

**Table 17 Alignment per Main Functional Category**

| Conversion | | |
|---|---|---|
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Cooling | Heating | Ventilating |
| Isolating | Industrial Processing | Driving |
| Drying | Energy Efficiency (general) | Monitoring & Controlling |
| Lighting | | |
| Reusing Energy | | |
| Efficient Mobility | | |
| | | |
| | | |
| **Production** | | |
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Producing Geothermal Energy | Producing Solar Energy | Producing Bio Energy |
| Producing Hydrogen Energy | Producing Fossil Energy | |
| Producing Waste Energy | Producing Wind Energy | |
| Producing Hydro Energy | Producing Energy (general) | |
| | | |
| | | |
| **Distribution** | | |
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Managing Energy | Transporting Energy | |
| | | |
| **Storage** | | |
| **No Alignment** | **Low Alignment** | **High Alignment** |
| Storing Hydrogen | Storing Electricity | |
| Storing Fuels | Storing Heat | |
| Storing Unspecified | | |

The results considering conversion show us 6 categories with no alignment between TSE and EIA: cooling, isolating, drying, lighting, reusing energy and efficient mobility. Furthermore there are 3 categories that are well aligned: ventilating, driving and monitoring & controlling. And finally 3 poorly aligned categories: heating, industrial processing and energy efficiency. Of these poorly aligned categories it should be noted that industrial processing is only low in EIA, heating is only low in TSE and energy efficiency (general) is low in both.

Production shows us 4 categories with no alignment, 4 categories with low alignment and only Bio Energy can be considered aligned. For distribution managing energy is not aligned and transporting energy is poorly aligned. Storage contains 3 categories that are not aligned (hydrogen, fuels and unspecified) and two low aligned categories (electricity and heat).

Within production one can spot interesting cases of immature technologies. Think for instance of ocean energy or the production of hydrogen as an energy carrier. These technologies are not present in the EIA list, but have been researched in the past under Pre-TSE and TSE policies.

Misalignment here could be explained by the fact that these technologies are not yet ready for market applications and do not appear on the EIA-list for this reason.

Since there is also a large amount of information covering pre-TSE projects and technologies, it is interesting to look at the alignment of Pre-TSE technology with EIA policy as well. Often it takes a couple of years for technologies to mature and diffuse. Therefor it is not strange when "older" projects covering discovery, development and demonstration show higher alignment with EIA which is largely diffusion oriented (recall Figure 4 Phases of Development for Technologies (RVO, 2014) in the introduction of this thesis). Based on the method applied in this thesis one can only observe the fact a bigger alignment occurs between the "pre-TSE" technologies and the EIA-technologies. The method in this research is not able to correct this relation for the amount of projects in the category. Therefor it could be a statistical flaw in the research.

## 8.4 Possible Explanations of (Mis)alignment

Through the previous paragraphs one could have spotted a number of explanations for misalignment. This includes cases with no alignment and some cases with low alignment (as specified in section 8.1). These low alignment cases can be explained by different arguments. Table 18 gives an overview of these explanations.

First of all, it could be that one technology (in this case it could both be a functional technology or a physical component) is the dominant design in a specific energy area. A dominant design is seen as a superior technology that is by far economically more efficient than competing technologies. Therefor this technology is applied in almost all cases and the effort of companies changes from R&D to process improvements (Abernathy & Utterback, 1978). Think for instance of the dominance of heat pumps in heating technologies. The dominance of one technology causes a low variation in technologies that should be supported and thus a low number of technologies on the EIA-list. On the contrary this technology should be filed in a high number of cases.

**Table 18 Explanations for Misalignment**

| # | Name | Explanation |
|---|---|---|
| **1.** | Dominant Design | Often with production technologies and categories that contain a low amount of EIA technologies. |
| **2.** | Immature Technology | Technology in this category has not matured from RD&D (yet) and does not appear on the EIA list. |
| **3a.** | Policy Decision: Fully Developed Technology | The technology has been subject to extensive RD&D in the past and decided to support no more |
| **3b.** | Policy Decision: Technology with Limited Economic Potential | The technology has no perspective in the context of the Netherlands. |

Second there are technologies that have been supported in the past by Pre-TSE and TSE, but do not appear on the EIA-list. These technologies have been support through R&D effort, but still these technologies are not yet mature enough to diffuse in an economically efficient way (examples are hydrogen and ocean energy technology to be found in section 8.3.2). This could be because the technology needs improvements through further research or demonstration projects in order to get to the diffusion phase. As a result more effort is put into the first three steps of development and less effort in the diffusion or deployment phase, which is covered by EIA.

For the third explanation we look at policy decisions considering the misalignment of EIA and TSE. This is a very interesting explanation since it really allows influence of policy makers to change the policy. Still there are two reasons why policy makes should not be worried about misalignment. For starters it could be that a technology has been stimulated through a large extent in the past. This technology has reached such a high standard that new policy support is not necessary; the market supports the innovation itself (Arrow, 1962). In this kind of cases it could be that innovation subsidy is not justified since no market failure occurs

Finally it could be that the technology has been ignored for support deliberately: this is the case for fuel cell and hydrogen technologies. These technologies have limited economic potential in the Netherlands and are therefore not part of the Top Sector Energy Policy. This is a deliberate strategic coordination decision of the politicians, which are aware of the fact that only limited budgets are available for innovation, and as a result, choices in the supported areas have to be made (see also the part about the TSE in the Introduction and Appendix A Introduction Top Sector Energy). Seen from the perspective of the policy maker this is not misalignment but an act or coordination (see also section 2.1.1 Alignment)

# 9. Future Usage of the Classification System

In the previous chapters I worked my way from a problem statement through theory in order to construct a model for technology comparison and monitoring. This method was specifically designed in order to classify and compare TSE projects and EIA technologies. Generally the method can be used to classify and monitor many different sets of technologies that are stimulated in a variety of policy instruments. It facilitates the content registration process, which forms the input for policy evaluation, policy advice and alignment of innovative practices in the Netherlands as a whole. In order to come to the best performance the method should be implemented as a general monitoring tool within the energy projects of RVO and the Dutch energy innovation community. In this way the most complete overview of energy technologies can be created.

## 9.1 Aligning the Public Funding System

The public funding system is organized among stakeholders from both public and private worlds. Together these actors fund, execute and coordinate innovation projects. Lepori (2011) distinguishes four layers within this system (Figure 16 Stakeholders in the Public Research Funding System and Appendix E); the policy layer, agencies layer, performing organizations layer and research groups and individuals' layer.

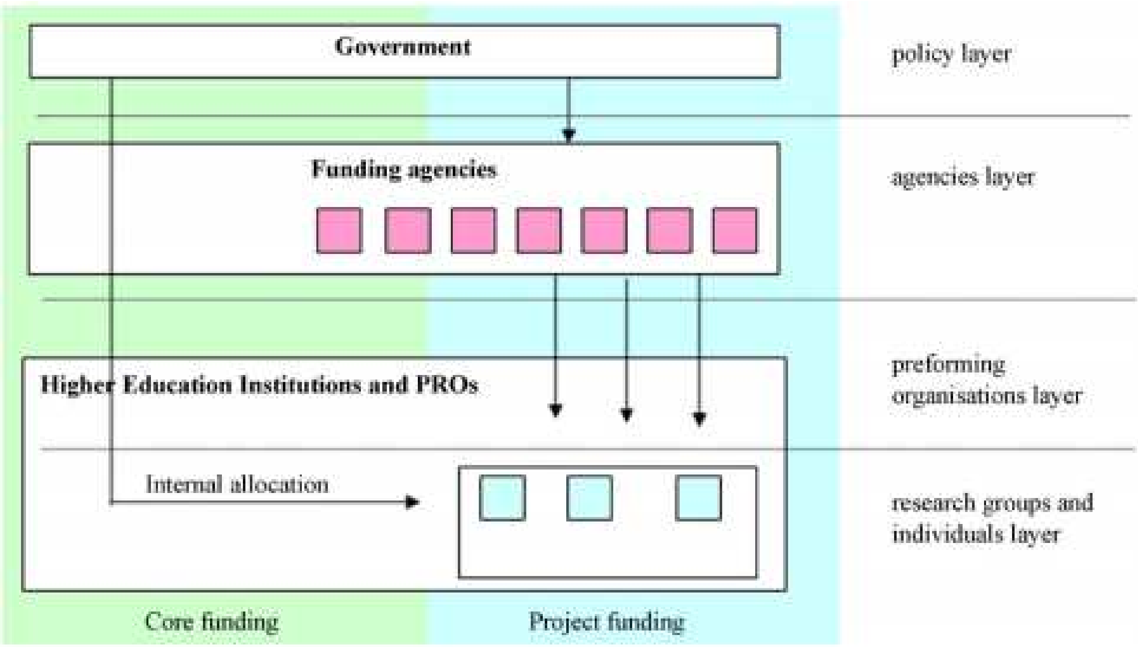


**Figure 16 Stakeholders in the Public Research Funding System and the allocation of funds (Lepori, 2011)**

The whole actor system of public funding can be seen as a national innovation community. The term innovation community refers to *"organizations directly and interdependently in commercialization of a new technology"* (Lynn, Mohan Reddy, & Aram, 1996). Within this community actors have to collaborate in order to align their interests regarding the policy that they are subject to. This is exactly the case within the Topsector Energy, where the national government has to collaborate with commercial parties and research institutions to commercialize new technology. In order to do so national policy has to be aligned with private party interests in R&D

and secondly projects executed by private companies have to be aligned with national policy. Consequently it is necessary to efficiently exchange information between all these stakeholders. This can be done using a content management system, in which information about projects is exchanged within the community. This can be partially based on the classification system as designed in this thesis. It will allow the innovation community to register their projects using a standard vocabulary for their subject.

## 9.2 Information Exchange for Evidence Based policy Making

Although collaboration in a community, as such, is more complex than just efficient information exchange, well organized information flows enable decision makers to come to better decisions (Alalwan, Thomas, & Weistroffer, 2014) and moreover high quality information is necessary in order to better review and analyze policy (Shaxson, 2005).

As can be read in the previous paragraphs policy making in the Topsector is done with limited amount of empirical data. Furthermore efficient information flow is necessary. The process of policy making currently depends on the input of stakeholders from the TKI's and advice of the RVO (see Appendix E Stakeholders in the Public Funding System). This makes the process vulnerable for subjective interests.

In order to prevent subjectiveness there is a need for more empirical and objective evidence. A broadly accepted term for this is called 'evidence based policy making' (Head, 2010). According to several authors this is beneficial for the quality of the policy. If used properly, the information gathered by the method will be less subjective than the information that is used to design current coordination systems.

In this way it can support policy makers in their decision making process and make it less dependent on subjective organizational factors. A content management system that builds a database consisting of all public and privately funded RD&D projects would be an ideal support tool for evidence based policy making, this can also be referred to as a technology portfolio. Using a technology portfolio is the ambition of the TopTeam Energy and will lead to better policy, better coordination, better alignment of RD&D activities and thus to more successful innovation. Although this requires a continuous cycle of updates of the database and related policy changes, all stakeholders are supposed to have interest in evidence based policy making.

## 9.3 Challenges for Future Usage: Implementing Content Management in A Community

As mentioned before policy should ensure alignment by coordinating innovation activities of all stakeholders. Policy will be based on the gathered data in the portfolio and thus be adapted according to the registered RD&D efforts only. Therefor it is necessary that this information is shared and registered among innovators.

One of the features of the classification system used in this thesis is that it enables content management of projects. Content management is a possible method to create the necessary efficient flow of information. The flow of information is crucial for successful evidence based policy development (Head, 2010) and decision making (Lynn, Mohan Reddy, & Aram, 1996). Creating content and information is more difficult than one thinks and requires an organization or community to manage this process properly. This includes thinking of a proper content management strategy. The Topteam already proposed portfolio management based on structured reporting as an important instrument (Topsector Energie, 2015). Especially reporting requires consistent information input. A proper content management system can be implemented to provide this information input.

The process of sharing and registering information is difficult, since it involves the input of many different stakeholders (Figure 16 Stakeholders in the Public Research Funding System and the allocation of funds (Lepori, 2011)). As a result the problem is not restricted designing a technological system. Moreover the success of the alignment effort largely depends on the willingness and acceptance of stakeholders to use a similar content management system.

First of all the stakeholders involved should be convinced to share their project information. Therefor implementation and expansion of the classification system should be approached as a process. According to De Bruijn et al (2003) there is a difference in dependency between hierarchical and network relations. Whereas projects supported by directly RVO are most dependent, these are the most likely to collaborate and share information. Actually this already happens so consequently the projects advisors of RVO are the first users to be convinced to work with the registration system.

Next to that, collecting and registering the information of projects funded by RVO and Research Institutes can be considered a big challenge. These projects do depend on public funding, so the government has a stake to demand collaboration. More difficult are innovation projects in which the government is not involved. Generally the content of these projects consist of confident and strategic information for its owners. The implementation of content management systems can be considered a hard practice with multiple challenges (Hullavarad, O'Hare, & Roy, 2015); the implementation of such a system among multiple actors can be considered an even bigger challenge than just the implementation at one organization. Therefor a critical mass of users should be reached first (Markus, 1990). As a result it should be easier to convince stakeholders with bigger concerns regarding the system.

The willingness of private companies to share information and collaborate in the implementation of the system could be problematic. For this reason it is important to sort out the different interests in the energy innovation community first. This could be done by doing more research regarding the implementation of the system in RVO and external companies. Based on the research of the interests, a detailed and stepwise approach for the implementation could be made. This can be done by carefully designing a process that genuinely guides all actors to acceptance of the classification system in order to get to consistent registration of project content. Unfortunately this falls out of the scope of this research and opens up directions for future research.

# 10. EVALUATION

For now we have discussed how this research assesses the alignment of the Dutch Energy Innovation Community. The features of the classification system focus on mapping the projects that have been executed in the previous year and how these projects can be used in order to adapt future policy. This has a positive effect on the alignment of policy instruments of the Dutch Government or the innovation community as a whole. Still there are ways the system and its purpose of alignment could have a less effective influence. The question arises whether this failure will occur on the functional and usability of the system, which we see as the engineering oriented side of the system, or the way it diffuses and gets accepted into society, which we see as the actor oriented side. These will be discussed in this chapter before actually evaluating on both aspects separately.

## 10.1 HOW TO EVALUATE A MEASUREMENT TOOL FOR ALIGNMENT

Within this research a classification system has been created that is capable to measure the alignment of technology in Dutch Energy innovation policy. Although the classification system works and is fit for purpose, it is understood that the system is certainly not perfect. This requires one to evaluate what the system is capable of and what are the limitations. This aspect can be assessed from an engineering perspective looking at functionalities and a more social perspective which includes the influence of human factors.

Engineers tend to evaluate systems from their functional requirements. This emphasizes on what the system does and what it is capable to do, how it should be produced and to a much lesser extent how people should use the technology (Blanchard & Fabrycky, 2006). This approach is mainly usable for engineered systems in the most technical context and minimal interaction with humans. One could think of large scale industrial installations and manufacturing technologies. This is not the case for the classification system as used in this system. This is much more related to information technology.

Information technology requires much more input from humans and the success of information technologies is often linked to its acceptance by users. This is distinct from the engineering perspective which simply assumes that humans will accept the technology and learn how to work with the technology they get in hand (Arntzen Bechina & Nkosi Ndlela, 2007). Information technology requires more attention to the social and institutional aspect of the technology and its interaction with the human environment. This is why human computer interaction scholars put emphasis looking at the personal usability as a key to successful implementation, besides functionality (McNamara & Kirakowski, 2006).

Some institutional scholars, according to DeSanctis and Poole (DeSanctis & Poole, 1994), even add even more social aspects looking at the social processes that interact with technology. Through this view, theories evolved on how technology causes organizational change in a social way. Furthermore Gutek et al (1984) put the emphasis on the importance of communication of the technology by the people that use it instead of putting the power in the technology. Therefor it is better to understand the way it is connected to underlying strategic goals of the organization and its people instead of the way technology meant to guide the change within the organization.

As a consequence two aspects will be evaluated: the functionality and the usability. Next to that, the social organizational influences of the classification system will be discussed as part of the usability aspect since it emphasizes on the user aspect. The functionality aspect will be extended by not only looking at what the technology currently is capable to do, but also its potential. The usability aspect will include the current effort for improved interaction with the technology. Secondly it will look at the connection with underlying strategic goals and how these goals could help to reach implementation in the future and the social structures this could help to emerge.

## 10.2 Evaluating on Functionality

Functionality describes the classification system as what it is capable to do (McNamara & Kirakowski, 2006). This section is therefore mostly describing to what extent the system could fulfill the functional requirements of this research as presented in sections 2.1.1-2.1.4. But also includes the functions that it could perform in the future by referring to aspects of the future usage of the classification system.

### 10.2.1 Current Functional Capabilities

The classification system was used in order to measure the alignment of policy instruments. The industrial RD&D support provided through Topsector Energy tenders and projects was matched with the deployment instrument Energie Investerings Aftrek (EIA). As stated by Bailey (1994) classifying technologies in both instruments allowed a structure comparison. A morphological approach (Ritchey, 2011) to the classification problem was applied. This classification has proven to be capable of measuring alignment, furthermore the system in its current form has proven to be capable of classifying all projects of the RVO database of projects from 2005-2014, nonetheless this required some adaption to the approach using a morphological analysis. This was due to innovation as to be discussed in the next paragraph.

As part of the functional requirements within the problem statement (section 2.1.2-2.1.4) innovation has been mentioned as a threat to the classification system. A standard morphological analysis (Zwicky, 1947), usually only describes the physical structure. This helped to decompose projects where it consisted of multiple components. Design theory (Suh, 1998), (Erens & Verhulst, 1997) added the functional view on technologies to the classification method. As a consequence immature technologies without physical representation could be classified based on their function instead of physical assembly.

One aspect of innovation has not been directly solved within the classification system in its current form. This is the classification of future new functions. The study limited itself to existing projects in EIA and TSE and did not study projects out of this scope. In the future new paradigms of technology could occur (Dosi, 1982). Think for instance of the field of smart grids and energy management for consumers, which was not part of the energy system in the past, because technologies covering this simply did not exist. Therefor it can be that no class exists for these technologies. This can be solved by maintaining the classification system by revising the functional and physical classes every once in a while. The means that the technical system should maintained by human interaction with the system. It should be stressed that no structural changes to the system will be made. The yearly update of new TSE projects can be an excellent moment to do standard maintenance or revision.

### 10.2.2 Points of Consideration for Future Usage

As mentioned in the introduction of this section the classification is capable of mapping the content of project of the public funding system for energy innovation; these are generally the output of an interaction between multiple stakeholders. Therefor it is important to state that the classification system is a tool to measure technology alignment. This can be an indicator for organizational misalignment in the public funding system, where actors are not working on projects as coordinated by policy or hard institutions. It cannot be used to actually map and deal with organizational misalignment

As a result organizational alignment of the energy innovation community could emerge as the method diffuses into different parts of the public funding system. The information in the classification system can become a future tool to overcome organizational misalignment. By providing insight in all practices of the energy innovation community, alignment could be reached earlier since all (or at least more) information is available to stakeholders and decision makers.

Furthermore mapping the soft institutional aspects (Negro, Hekkert, & Alkemade, 2012), like shared values and norms among innovators would be an extra feature, but this is not incorporated in the classification. Also this would require other methods and a more institutional approach towards the problem, which could be part of future research and improvements, but are not directly incorporated in this research approach and method.

### 10.2.3 Conclusion

Concluding it could be said the classification system is capable of measuring the technological alignment of current projects, including the innovative ones. The internal structure allows classifying of current and future innovations. Organizational alignment falls out of the current scope, but technology misalignment can be seen as an indicator for organizational alignment failures. As the classification system diffuses into the energy innovation community, it could provide means to overcome organizational misalignment through evidence based policy making.

## 10.3 Evaluating Usability

A successful technology or classification system is used by many people. As mentioned in section 10.1 the usability therefor is a very important aspect. A usable classification system for instance will reduce the number of human errors or the time necessary to learn how to work with the system. In order to evaluate the usability the classification system in this research, I will elaborate on the actions that are undertaken in order to make it usable and what could be done to further improve the usability in the future.

### 10.3.1 Current Actions for improved Usability

First of all an effort is done to explain how to use the classification system, since the actual classification procedure is an import step to be able to perform such an analysis. The procedure (section 6 Application Procedure) can be seen as a manual or user guide that helps the user to register the projects in a similar way as is intended in this research.

Furthermore training material has been produced in section 7 (Application of Classification Method. This not only presents standard cases, but also 5 types of difficult cases in classification are presented (7.5 Types of Complicated Cases and their Solution). The training material includes examples of all types of complicated cases and their solutions. Both aspects helps the users to make the model do what they want (McNamara & Kirakowski, 2006) as is the intended purpose of usability.

### 10.3.2 Points of Consideration for Usability

In order to further reduce the problems caused by limited usability, certain actions could be executed to improve the classification system in the future. These actions will improve the ability of people to use and accept the classification system as it is.

An aspect that is not covered is the user interface, through which the registration would take place. The design of a usable interface is necessary for clear communication of the technologies intentions (DeSanctis & Poole, 1994). The researcher stuck to a table of columns and rows in which the content should be registered; making registration not easier for one who is unknown with the exact meaning of certain terms. It would be logical that RVO.nl uses its content management system Docbase to provide users with the necessary interface on how to classify the projects by sticking to a certain amount of options.

Furthermore in the consistent application of this method and its usability can be found in actual training of the future users (Kushniruk, Myers, Borycki, & Kannry, 2009). This should be done in a workshop type of settings. Within this training the researcher could provide direct feedback to the user on how to classify certain projects, helping the user to overcome problems and learn how to work with the system faster. Through direct communication and feedback also more support for the use of the technology could emerge. Another benefit of training would be not only feedback to the users, but also to the designers. By training users and by users that actually use the system more and more uncovered features will become clear. This would require the designer to make small changes to the manuals or even the operational model itself. Improving the design of the system manuals in concordance with its users would be a great additional feature, but a very hard one to realize.

A next step in the usability aspect would be by taking care of the communication surrounding the implementation. Once users are informed of what the system would be used for they would pay greater attention and dedication towards learning how to use the system. This touches the aspect of emerging social structures (DeSanctis & Poole, 1994) considering evidence based decision making. This is an example of a social structure as mentioned by DeSanctis & Poole (1994). In chapter 9 this is discussed as a strategic goal supported by evidence based policy making (Head, 2010). The content management features of the classification system make the emergence of a social structure considering empirical decision making possible.

On the contrary collecting this information requires overcoming the challenge of implementing of the classification system at the different actors of the innovation community. The implementation of a content management system in a single organization can be considered hard (Hullavarad, O'Hare, & Roy, 2015), implementing it in a community is even harder. This requires it to be connected to the strategic goals of these stakeholders as well, making it a more complex problem. More research is necessary to understand whether the stakeholders of the innovation community are really intended to implement the system and register their projects according to it, before one starts to roll out the system externally of RVO. This would probably require working examples of the current system as well.

Furthermore, for RVO, it is necessary that the classification system is accepted by users in the internal organization as well as external organizations (see 9.3 Challenges for Future Usage: Implementing Content Management in A Community). With a well-functioning, usable classification system it should be easier to convince both internal and external stakeholders to use the classification system. Both functionality and usability aspects are crucial for a smooth implementation and one should be aware these two aspects are considered all the time. The more actors that should use the system the more complex the problem becomes in terms of functionality and usability. As a result this includes the implementation at internal RVO practices first before going to less and less dependent stakeholders. This should be done to reach a critical mass of users before targeting groups that are more difficult to convince.

### 10.3.3 Conclusion

Concluding it could be said that a lot of effort has been put on the guidance of users through the classification system through manuals and training material. For now it is important to teach the users how to use the classification system with on the current available material. For the designer it is important to adapt the training material in the future, based on the questions of these users. For RVO it is necessary to take care of general acceptance of the system both internally and externally if it wants to be capable to align the actions in the energy innovation community.

# 11. CONCLUSION AND RECOMMENDATIONS

Policy alignment is a well-known problem when stimulating innovative technologies. Policy instruments should be aligned and they should, to a large extent, support the same or similar technologies within the energy sector. Misalignment results in the effect that investments are not used efficiently and the economic growth is not optimized. Constant alignment of policy instruments is thus necessary, as well as the resulting alignment of innovation practices supported by policy.

## 11.1 CONCLUSIONS

In this research alignment was approached from a technology perspective. This approach is chosen find out whether TSE and EIA policy are aligned in terms of technologies they support. In order to identify consistency and coordination issues related to alignment, a method for technology comparison is required. As a consequence a classification system for the content of technologies and technology project was developed that could be used as an alignment measurement tool. Furthermore this resulted in the following research question:

*How can innovative energy technologies be classified and compared in order to analyze alignment of policy instruments now and in the future?*

This question and approach of alignment requires a classification of the projects and technologies in both instruments based on their technological content. In order to solve the problem a morphological analysis was used as a methodological approach. Next to that the classification issue was separated in smaller issues regarding the technology classification. It embeds the actual classification issue, dealing with hierarchical technologies and dealing with innovation of technologies. First of all in order to make a technology classification system it is necessary to understand how technologies can be described. Product and system design theory describe technologies from a functional and physical perspective as is applied in this research. Secondly one requires understanding of the hierarchical character of technology and complex technological systems. Since technologies can be decomposed into endless hierarchies, one has to determine one or more levels of comparison that are applied in a consistent manner. Finally, since innovation can take place at any level in this hierarchy, it is necessary that a classification system for technologies is capable to be applied in a more and more detailed setting; in this way future innovations and improvements can be mapped as well.

A literature review led us to theories of product and systems design. Concepts from product and system design created the basis for the method that makes it possible to compare technology projects in the TSE-policy with EIA-policy. As a consequence the classification is approached as an inversed design process. First physical decomposition of products will be done and secondly physical technologies will be assigned to a functional class. This will be done on every hierarchical level. Both will be classified in pre-defined functional and physical classes, which form a strong relation: certain physical classes belong to one or a limited amount of functional classes (and vice versa).

Approaching the classification as an inversed design process resulted in a conceptual model based on pillars, layers and levels. The functional and physical hierarchies form pillars of classification.

Within these pillars multiple levels can be distinguished that correspond to the classification categories. Furthermore the combined levels of the physical and functional hierarchy together form a layer. In order to compare EIA and TSE this research classified technologies along two layers. If necessary these classes can be extended to higher or lower layers, depending on the detail one requires for analysis.

Another part of the conceptualization phase was the development of a procedure to secure that repetition of the classification practice is possible. This procedure extended the original conceptual classification model for analysis of alignment, with guidelines for classification of projects and technologies in RVO. For classification it is necessary to decompose the physical technologies first, before assigning a functional class. This helps to deal with multifunctional cases and furthermore makes it possible to include new data for future analysis in a similar way as done in this research.

The method, including the comparison model and application procedure, enabled us to analyze the current alignment of EIA and TSE policy. The main functional level analysis showed the most usable results; spread over 4 functional systems (conversion, production, distribution and storage) 12 functional categories were found to be unaligned within TSE and EIA, 10 were found to have poor alignment and only 4 categories were aligned. Due to this high amount of misalignment, further desk research was conducted. This helped us to understand that his was due to deliberate policy decisions or natural circumstances (for instance the existence of a dominant design, an immature technology or policy decision to no longer support a fully developed technology or technology with limited potential). One could thus not fully rely on registration and comparison of project, but should always look for other explanations. Nonetheless it was found that managing energy is the biggest blind spot on the EIA-list. This functional category contains energy management systems that enable the implementation of smart grids.

Evaluation of the classification system made one aware of the aspects that the classification does and does not cover. The classification system is capable to classify the current project of RVO on their technology. This includes the ones without a physical representation in the real world. Also non existing functions can be classified along the same methodology, although this requires slight maintenance over the years. With respect to alignment, it should be clear that only technological misalignment can be measured using the outcomes of the classification system. The analysis will reduce misalignment to a limited amount of functional categories, in which organizational misalignment could play a role. The underlying organizational misalignment in the public funding system cannot directly be measured.

Nonetheless one could conclude that alignment of policy instruments could be studied from a technology perspective. Innovative energy technologies can be compared using a model composed of related physical and functional pillars, using multiple levels and layers, dependent on the detail required for analysis. Innovation can be dealt with within this methodology.

## 11.2 Recommendations

Recommendations of this research are twofold. By performing a study on the alignment of two policy instruments it has been proven possible to study alignment from a technology perspective. Now it is important to implement the methodology and to make it usable for daily practices and decision making. In order to so, recommendations cover aspects of implementation for future usage and improved usability.

As mentioned before, an analysis of alignment gets outdated as soon as new project will be initiated. As new projects occur and the EIA policy is updated, the database that is used for analysis should be updated as well. Therefor it is recommended to implement the registration method in daily practice of RVO employees. Registering projects along this methodology enables RVO to continuously monitor the content of its projects.

Secondly in order to maintain consistency in the database it is necessary to appoint someone to be responsible for the content of the database. This person needs to be capable to classify projects, spot inconsistencies in the classification done by other and be able to add new functional or physical categories if necessary.

Thirdly, as policy makers, funding agencies and research performing organizations can use the information to align their activities, evidence based policy making is of interest of more stakeholders than just RVO. Evidence based policy making based on the registered project content will help to coordinate of research activities and further alignment of these activities.

From a user's perspective it should be understood that a classification system could only work when the users are capable to work with it. User manuals and documented cases are current examples of practices that could help users to understand how to use the classification system.

In the future these should be extended by training sessions which help users and designers to improve the method. Therefor it is recommended to put extra attention to the usability aspect. For instance training session could be given or the system could be communicated to users as a tool by which strategic goals like evidence based policy making and decision making could be reached. This will increase the acceptance among both internal and external users to use the system.

# 12. REFLECTION

Within this section I will reflect on the work done in this thesis. First of all I reflect on the chosen approach. Secondly I will reflect on the scientific and practical aspect of this thesis. Furthermore I will reflect on the deliverables and finally I will reflect on my personal experience as a graduate student.

## 12.1 REFLECTION ON APPROACH

Within this research the starting point was a very practical question of RVO. The question was whether one could see the technologies, as developed in the Topsector Energy Policy and its predecessors get continuously stimulated on the EIA-list. Both support subsequent phases in the development of the technology. In order to answer this question it was chosen to look at the hard institutional aspect. In policy terms this is called alignment of policy instruments, which also is a central topic of this thesis. It was chosen to approach this problem from a technology perspective. This meant that all technologies that are part of the policy, mostly embedded into projects, needed to be classified according to their technological content. This is something that is not done regularly, since most projects are only registered according to their policy aspect or financials.

Moreover as stated in the evaluation, misalignment had to be mapped first before it could be dealt with. A technology misalignment measurement tool helps the policy makers to identify misalignment in an earlier stage. In this way valuable time and money could be saved by being able to appoint misalignment and pinpoint at the weak parts only. The technology alignment approach thus delineates the problem to a smaller topic of concern.

Next to that alignment is usually approached from a more soft perspective, in which it genuinely analyzes the misalignment or lack of coordination between people, companies or company departments. I referred to this as organizational misalignment, looking at the actors performing innovation. In this type of misalignment, the misaligned parts of the organization are aligned through reorganization or other efforts to improve collaboration. Especially the last aspect of improved collaboration uses a more process or actor oriented approach to tackle the problem. This could be by improving the collaboration of actors along the development of a certain technology. Since this research was an effort to measure the alignment of technologies stimulated by policy instruments, this actor oriented approach falls short here: topic related misalignment issues had to be identified first. Process management approaches can be a subsequent step in dealing with the issue of misalignment in the Dutch national energy innovation policy.

Furthermore alignment could have been approached from financial or policy perspectives. A financial perspective would look at the alignment of financials spent on every instrument or, on a deeper level, on the financial spent on every instrument per topic. This second part would require technological classification as well to be able to measure alignment. From a policy perspective one would be interested to see whether the policy is capable to coordinate the actors within the innovation system. Also here a comparative study of policy intentions and projects as executed by the innovators would require a technological classification in the basis.

Taking the previous parts into account I am confident that the right approach is chosen. Technology classification is the best way to map the content of innovation projects in the energy sector to make although it requires a very large database it is the most suitable approach to identify misalignment in parts of the sector as supported by the government and to deal with policy misalignment. Organizational misalignment can be solved in a subsequent step using more soft approaches to solve the issues that might have occurred among innovating actors. Also financial and policy related alignment issues could be solved as subsequent action to the classification of projects on technological content.

## 12.2 Reflection on Scientific Aspect

Within the classification approach certain methods have been combined in an effort to solve the problem of mapping alignment. First of all, the morphological approach allowed us to decompose and classify technologies into physical component parts. Furthermore the addition of design theory, and its functional view, helped to even decompose and classify innovative technologies with no physical representation yet. This allowed comparison of both existing technologies and technologies that are in development.

Next to this an addition to the technology innovation systems approach (TIS) can be made by providing a view on the delineation of the technology part of the innovation system. A lot of different technology delineations are made by TIS scholars. It thus lacks of a consistent description of technology. This description is done in this thesis by describing technologies in a functional and physical way. TIS scholars can use the same approach in their analysis of the socio technical context of an innovative technology. In this field the interplay between technology development and technology developers is the most important aspect.

Furthermore within the TIS approach, structural failures of the innovation system are often mentioned and listed. As a consequence of the inconsistent delineation it is hard to develop empirical methods and tools to empirically measure these structural failures. Policy misalignment is one of the failures as listed within the literature and the morphological analysis in combination with design theory helped to map and measure alignment in the full energy innovation system. A TIS approach would have required a part by part analysis of the different sectors within the energy sector, with a less substantiated empirical approach. Although our analysis is broader than one specific technology, the alignment aspect is covered with greater attention than a TIS analysis has ever done.

## 12.3 Reflection on the Practical Aspect

The technology perspective approach was chosen for the context of RVO, looking at the technologies within policy instruments. As a consequence it was chosen to develop a classification system that could be used to measure alignment of policy instruments.

The technology classification system enables RVO to analyze its project on a more detailed level and over a longer time than was previously possible. The current time span of policy evaluation remained to a single instrument. Where instruments are changed every 3-4 years (time span of a political cycle), the maximum evaluation time was equal to this. It is thus of great value to enable policy makers to evaluate on the policy they designed over longer periods by providing, a policy wise, robust classification system.

Furthermore the practical goal of this thesis was to design a usable technology classification system. This system should not only be able to analyze the current question regarding the comparison of EIA and TSE projects, but should also enable future users to analyze their projects along the same line of thought. This requires a consistent application of the same registration method. Within the evaluation chapter of the thesis, the effort for providing a usable solution was discussed by appointing the practical value of an application procedure and training material, but still a lot more effort need to be done in order to make it usable for implmenetation.

Concluding it could be said that not only the current problems of project registration based on content have been tackled by taking the technology approach. Furthermore future technologies could be classified along the same methodology. New problems occur as the method needs to be used in consistency by multiple users. Future effort regarding the implementation and usability of the method are necessary to actually use the classification system consistently for policy evaluation and alignment practices.

## 12.4 Reflection on Personal Challenges

Writing a master thesis has been the hardest thing I have done in my life so far. This caused that a lot of personal challenges were faced during the process. First of all I got confronted with my own ambition. I did not only want to do a master thesis within a company, but tried to maintain my extracurricular activities as well. As a result I learned to plan my activities better but also accept the fact that, in some cases it is better to take some more time. Of course sometimes this time is not there, but when it is there use it!

Furthermore I learned to approach a problem in a methodological and structured manner. This is something that is absolutely necessary when you leave the protective environment of the university and its structured courses behind. Delineation of the problem and choose of sufficient methods and theory is a serious hard task. On the other hand this thesis provided me with insight in their strengths as well.

A third thing I learned the necessity of writing a convincing argument. The thesis showed me it is not important what you write, but how you structure and explain it and use it to convince your reader. Especially in this topic of systems engineering there is a lot of confusion about certain terms. Every actor has its own interpretation and thoughts with terms like function, system, product or component (just to name a few examples). Explaining definitions is a very important aspect of the argument one uses to communicate its design.

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# APPENDIX A INTRODUCTION TOP SECTOR ENERGY

TSE stimulates technologic innovation projects, pilots and research in the energy sector. The ambition of this policy framework is to reduce $CO_2$ emissions, improve efficiency and increase the amount of renewable energy technologies in the energy sector. The focus of the framework lies in the first three phases of technologic innovation (see Figure 1 discovery, deployment and demonstration):

- Discovery phase in which research is done through universities and research institutes to find new technologies.
- Development phase in which the technologic discovery is improved and made ready for "real world" applications.
- Demonstration phase where a consortium of stakeholders (mostly supplier and a launching customer) decides to test the new technology with a pilot.

| TRL | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Fase | Discovery | | | Development | | | Demo | Diffusion | |
| Onderwerp | Systeem | Functie | Concept | Element | Component | | Product | *Toepassing Exemplaar Markt* | *Gebruik* |

**Figure 17 Innovation phases as used by RVO.**

Subsidy is given based project plans that are submitted through a tendering procedure. Market parties can apply for this subsidy as long as they do this in a consortium. *The consortium should in most cases include a combination of SME's, large companies and knowledge institutes.* Each tender has a maximum budget, projects are ranked and subsidies are granted till this maximum is reached (RVO.nl, 2014b).

## TOPSECTOR ENERGY POLICY: MULTILEVEL BUILD-UP

The policy of the top sector energy and its predecessors (IAE & EOS) is build up as follows:

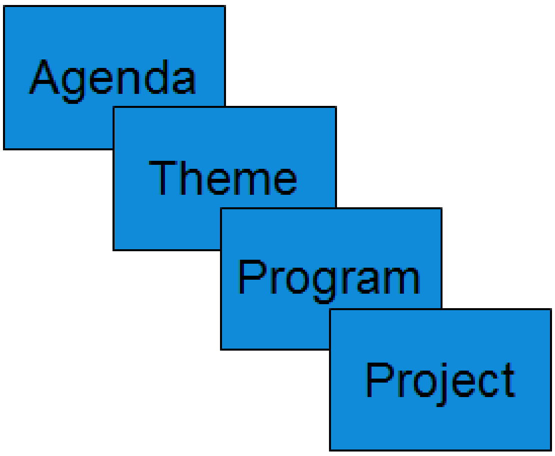



**Figure 18 Multi level build-up of Dutch innovation policy: From innovation policy agenda to innovation projects.**

| | |
|---|---|
| **Agendas** | With an agenda is meant a policy agenda. Policy agendas are drafted in order to write down a set of negotiated goals of the general government. The policy agenda topsector energy aims at “a clean and efficient energy generation that makes the Dutch economy stronger” (Topsector Energie, 2014). It is part of the general policy “topsectoren” as executed by the Dutch government. |
| **Themes** | Themes are sub goals of a policy agenda. In the top sector energy policy these themes are selected and constructed within so called TKI’s (Topconsortia Knowledge and Innovation). Together with knowledge institutes, enterprises and universities the theme is build up and a selection of relevant aspects is identified. Negotiation between these parties resulted in an innovation contract (TKI - EnerGO, 2014). |
| **Programs** | Programs or program lines are defined within the innovation contract (Topteam Energie, 2012). In the programs the sub goals of a theme are further operationalized. It describes an area in which actual projects can be conducted. This includes a roadmap and should result in a portfolio of projects that together contribute to the goals of the innovation theme. |
| **Projects** | Projects form the practical part of the policy. In this layer of the database all actual projects are gathered. A project is conducted by actors which can be enterprises, knowledge institutes, NGO’s or universities. In order to execute a project actors receive funding in the form of subsidy. The subsidy is provided on basis of a project plan as submitted by the actors engaged in the project.<br><br>Projects have a specific goal and ultimately result in a physical artifact or scientific contribution. Not only a working product or principle is seen as an artifact but a scientific article or report describing a working principle is part seen as such. Therefor projects can be seen as the place where the actual innovation happens. |

### CONTENT OF THE PROJECTS DATABASE

The database of the topsector energy contains data of the following policy agendas:

| Agenda | Time Span |
|---|---|
| **Energie onderzoekssubsidie (EOS) & Energietransitie** | 2005-2009 |
| **Innovatieagenda energie (IAE)** | 2008-2012 |
| **Topsectorenbeleid – Energie (TSE)** | 2012- now |

Within these agenda’s the following themes were supported:

| EOS | IAE | TSE (TKI’s) |
|---|---|---|
| Energy efficiency in industry and agro | Green Materials | Offshore Wind |
| Biomass | New Gas | Gas |
| Clean fossil or new gas | Sustainable electricity | Switch2SmartGrids |
| Building environment | Sustainable mobility | EnerGO (Energy saving in buildings) |
| Generation and grids | Value chain efficiency | Solar Energy |
| | Building environment | Bio based Economy(BBE) |
| | Greenhouse as energy source | Energy saving in industry (ISPT) |
| | Carbon Capture and Storage | |

Sources: (Decisio, 2010), (Energietransitie - Creatieve energie, 2008), (Topsector Energie, 2013).

### Content of the projects database docbase

Within a web-based database, called docbase, the projects of the topsector energy are stored. This happens along agendas and themes, which were renamed several times. An overview of agendas and themes over the years can be found in the tables in the previous paragraph.

The changes in themes make it hard to follow specific technology development. There are many ways to categorize technologies in themes. We can see some consistency, but for instance greenhouses are only explicitly mentioned in the IAE. Still innovation on greenhouses also happened in EOS and TSE.

Next to the categorization in themes and agendas we can find information about the innovation phase in which the project is operating (research, development or demonstration), the tendering program it has been part of and a short description of the project.

### Content of Qlikview database

Next to docbase the energy innovation monitoring team developed a second database, called QlikView, which is able to display the docbase-data in a visual representation. In Qlikview we cannot distinguish the categorization of projects along agendas and themes any more. This database is ordered mostly along innovation phases. Besides that it includes features to select projects that are addressed to specific technologies or technology groups (for instance heat pump, heat exchanger or heat recovery) or the 'old' configuration along tendering programs. Also more general systems like energy saving, or systems addressed to a sector (think of energy saving in industry) can be selected.

The data in Qlikview allows RVO to follow the technologies in their innovation development. The database contains TSE, EOS and IAE projects. This means it mostly covers RD&D phases and is limited when looking at deployment. By extending it with information collected in the EIA the database, RVO would be able to give a better overview of the deployment phase. Still the EIA data has to be adapted to the current database categorization, in order to integrate the two.

# APPENDIX B INTRODUCTION ENERGY INVESTMENT DEDUCTION (EIA)

EIA stimulates technologies in the early deployment/diffusion phase. The subsidy consists of a beneficial tax regime for, for instance, energy saving technologies or a bio-gasification unit. In order to structure this regulation a "list of technologies" is composed; technologies on this list are tax deductible and therefore more likely to be implemented by companies. Every year the list is refreshed based on the available technologies. Technologies, that have proven to be more efficient that its predecessor, are added to the list (RVO.nl, 2014c). Also norms and requirements are adapted when technologies become more efficient.

The EIA-list has five categories, each of which represents a group of technologies that capable of energy saving above a certain threshold level. The technologies are categorized along the system in which they are applied (system of application). This means certain technologies can be found twice on the list, but in different contexts. The categories are:

- Industrial Buildings
- Industrial Processes
- Transport
- Renewable energy
- Energy Advice

It should be clear that the fifth category (energy advice) does not contain technologies. It describes the possibility to also deduct the costs of a feasibility study. Within the five categories we find a functional subdivision of the technologies. Examples are: heating, cooling, ventilating, isolating, lightning etc.

## GENERIC AND SPECIFIC CODES

Within each of the remaining four categories a difference is made between generic and specific codes. A distinction is made in order to allow a faster handling of application. For technologies that are often requested it might be beneficial to make a specific procedure. Generic applications require a report with proof of the total energy saving. Specific codes allow the applicant to apply with less evidence than a generic application (Bongertman, 2014).

A generic code consists of a framework that sets the quantitative boundaries for energy saving measures (RVO.nl, 2014d). All technologies that fall within these norms are eligible for tax deduction. Within the generic code a difference is made between existing and new buildings, processes etc. For new applications the norm is stricter since "*that investment has to be done anyway*" (Bongertman, 2014). Within existing processes the incentive to apply the newest technology is less urgent and therefor a lower norm applies.

Specific codes do not only describe general norms of energy saving but do this on a technology specific level. The codes describe products or components of products. An example is code 211103 [W], which describes the functional requirements of a heat pump. The [W] describes this is the best practice in industry, as stipulated in the law, and allows no investment of a similar technology.

A special example is code 210000, this describes a package of measures for one industrial building. It allows companies to implement a set of new technologies at once. Basis of this code are the energy labels. The improvement, as a result of the new technologies, should be at least two labels.

### CHANGES IN THE LIST

As mentioned before the EIA is updated every year. A lot of technological knowledge is necessary to find new, near commercially ready, technologies. RVO.nl has two ways to come to a specific code

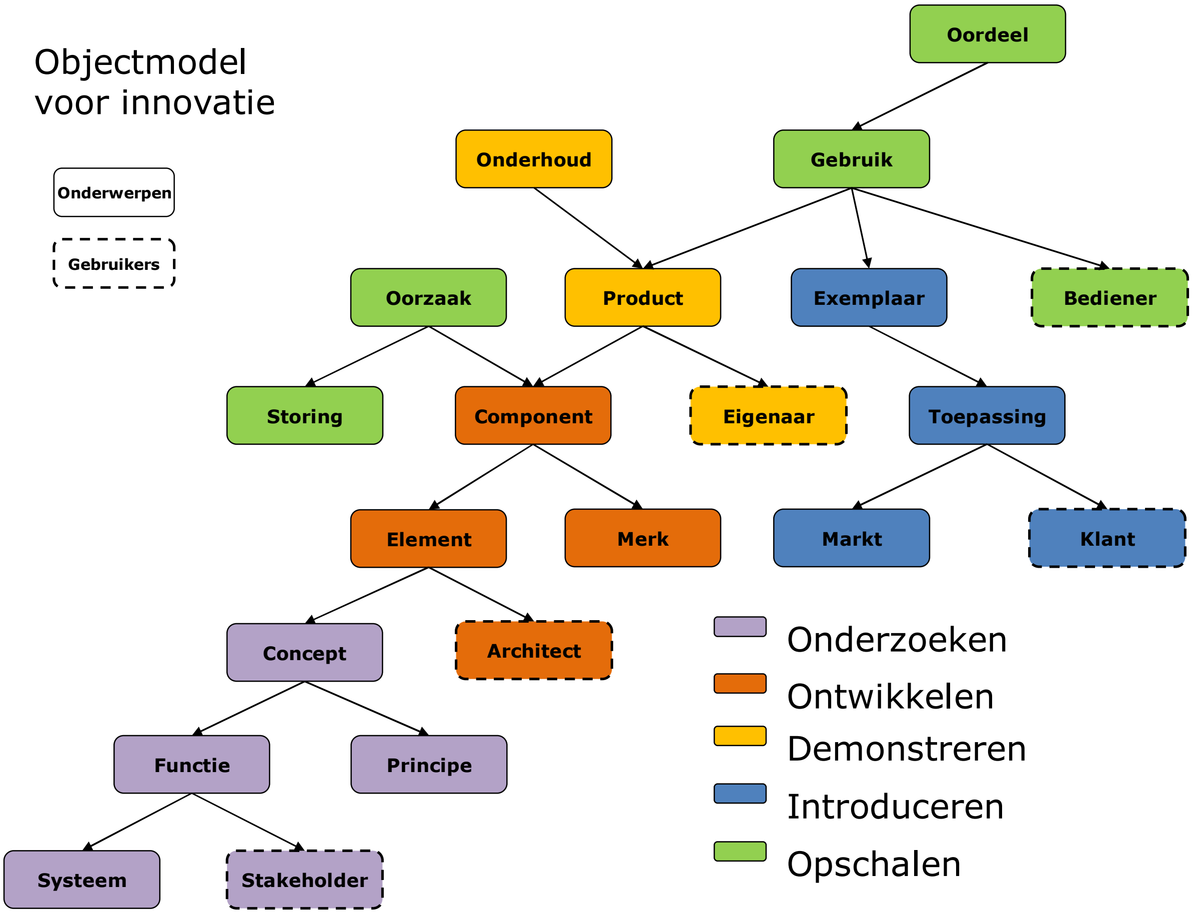
First of all, from the previous part, we can derive one part of the updating process: For a technology that is often requested under the generic procedure, RVO.nl looks at possibilities to design a specific procedure. Secondly RVO.nl tries to anticipate on new technologies. In corporation with the industry a selection of promising technologies is made. A good example of this is the Dutch horticulture sector. Every year a meeting with the branch organization, knowledge institutes and RVO.nl is organized in order to determine new technologies for greenhouses and its related business. A third way is the usage of empirical data, for instance of the TSE database or patent databases. This is done in a limited way.

Even though new technologies are added quite regularly, updating the current list is an action that is performed more frequently. Reasons for updates are the following (based on the 2014 list):

- Technology is made more specific
- Technology description has been broadened
- Subset of an existing technology on the list
- Adaption of the norm
    - Loosened restrictions
    - Stricter restrictions
    - Normal for market

Also technologies are deleted from the list. They ether became commercially ready, are obligated or are not used anymore.

# APPENDIX C OBJECT-MODEL




Below we will briefly explain the object model:

**Systems** form the highest aggregation level describing technologies. They are a combination of parts that logically are seen as one group, for instance energy production, distribution, storage or conversion systems. Within the system of "conversion" we find all technologies that are using energy with a certain purpose. One could think of electrical conversion or heat conversion.

**Functions** are seen as the multiple ways the system goal can be reached. For instance the use of electricity can be done using lightning or the use of electricity powered machines.

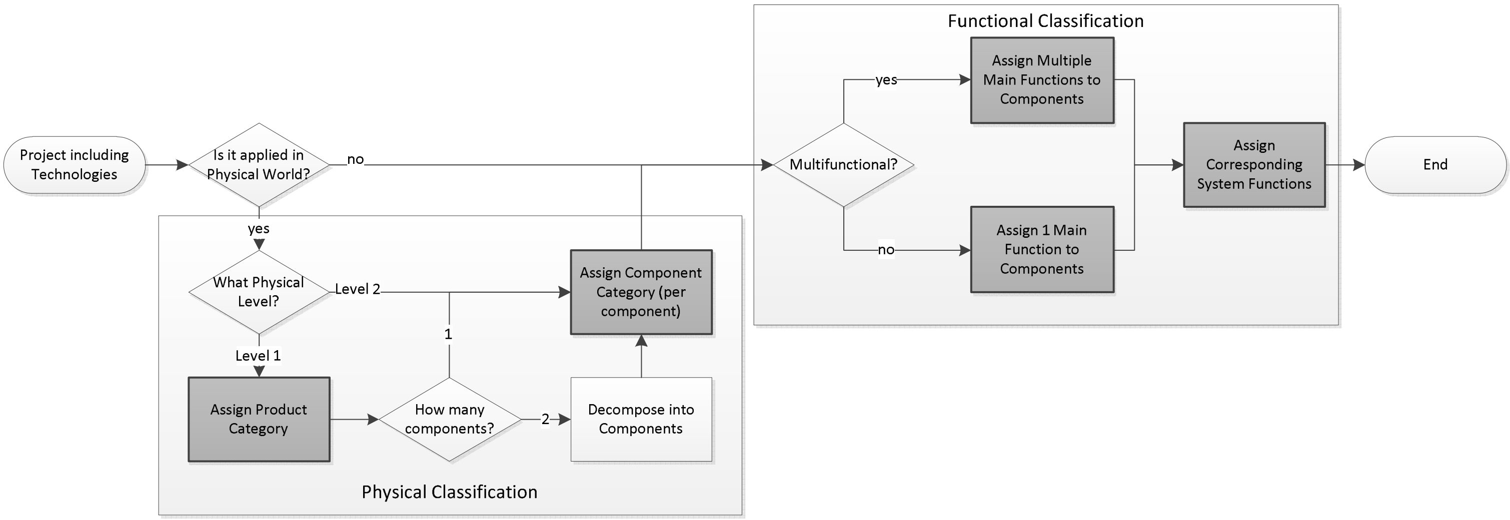
**Concepts** are the practical physical mechanisms that are used to fulfill the function as described before. This for instance could be lightning of a building using LED.

**Elements** are performance requirements that a future component or product should have in order to fulfill a role within a concept. One could decide based upon these to develop a component that is promising to reach the performance requirements.

**Components** are the physical decomposition of a product. For instance the type of diode used within a LED lamp. Different components can be innovated on.

**Products** are real existing artifacts in which several components are applied. Of these components one or more could be innovative.

# Appendix D Extended Application Procedure



# APPENDIX E STAKEHOLDERS IN THE PUBLIC FUNDING SYSTEM

This section will introduce the stakeholders involved in the policy making process. This will be done from the perspective of RVO. The information in this section is based on information of the Topsector Energy website and internal interviews.

## FUNDING AGENCY: RVO.NL

RVO can be considered as a government agency; its task is to execute the policy drafted by the Ministry of Economic Affairs. Secondly, RVO advices to policy makers about policy improvements and regarding the funding of innovation projects. In order to do so RVO is supposed to report the performance of projects, programs and policy in a systematic way.

Within RVO we furthermore distinguish between two types of internal actors; project advisors and policy advisors. Project advisors have direct contact with stakeholders in the performing organizations layer, where policy advisors have direct contact with the stakeholders in the policy layer. Both tasks can be executed by one person at the same time, but there is a clear distinction as to be explained in the next two paragraphs.

**Project advisors** of RVO receive applications of performing organizations. Due to their experience in the field they are capable of reviewing projects. The actual decision about a subsidy request is done by an independent committee, specialized in a specific field of application. By using a set of criteria the project advisor advises the committee whether a project can be subsidized. Secondly project advisor has the task of secretary in the TKI's in which the support on drafting policy for new program lines. Policy programs and related tenders run for short periods. Usually these are updated every year. Nowadays this is done based mostly on experience instead of empirical data, therefor the TKI is very dependent on the knowledge of the project advisor.

**Policy advisors** of the portfolio team are designated with the task to report and evaluate on policy programs and instruments of all TKI's. The portfolio team monitors and reports about the performance of policy to TKI's, Topteam Energy and the Ministry. Based on the monitoring data they review the drafted policy of the TKI's. The portfolio team focusses on all TKI's, therefore its advice is on a higher aggregation level than the previously discussed project advisors. For this they rely more on empirical data instead of personal experience in the field.

## POLICY MAKERS

Policy makers are stakeholders with the actual power to decide on changing policy. Three types of policy makers are distinguished; the Ministry of Economic Affairs (the formal policy maker of the Topsector), the TopTeam Energy (formally responsible for the performance of the Topsector) and the TKI's which are responsible for a specific part of the policy. Together the Ministry, Top Team and TKI's form the governance layer for the Topsector Energy.

### Ministry of Economic Affairs

The Ministry of Economic Affairs coordinates the general policy of the Topsector. The Ministry has a controlling role where it formally approves the policy drafted by the Topsector Energy. Together with RVO, the ministry has a portfolio management team, which advices the Top Team energy and the TKI's on the composition of their program lines.

## TOP TEAM ENERGY

The Top Team Energy consists of representatives from industry, knowledge institutes and the government. The Top Team has formal responsibility of the performance of the Topsector Energy. Together with McKinsey, the Top Team decided to organize the Topsector in a system of portfolio management. Portfoliomanagement contributes to the "*effective and expedient realization*" of the objectives of the Topsector by structured reporting and consequently structured decision making (Topsector Energie, 2015).

## TOPCONSORTIA KNOWLEDGE AND INNOVATION (TKI)

The Topsector is furthermore organized in **TKI's,** which are specialized in a specific field, think of TKI Biobased, TKI Solar and TKI building Environment (For an overview of TKI's see also Appendix A). Within this field the TKI organizes the collaboration between industry, research organizations and the government. TKI's compose program lines considering their field of expertise. Program lines coordinate the subsidies for projects and are updated and reviewed on a yearly basis. In total there are 7 TKI's that manage a total of 29 program lines.

## RESEARCH PERFORMING ORGANIZATIONS

The performing organizations consist of all actors involved in the practical execution of innovation. These are the actors that apply for funding and perform the actual research, development, demonstration and deployment projects. The organizations consist of researchers and research teams which together work on these projects.

There is a distinction between research institutes and private stakeholders. Since RVO is a funding agency it only subsidizes on a project basis. **Research institutes** also receive funding through direct governmental support (which is distributed between research groups internally), examples of research institutes are universities, TNO and ECN. **Private stakeholders** do not receive such direct government funding (Lepori, 2011) and have to fully invest themselves or by funding on a project to project basis.

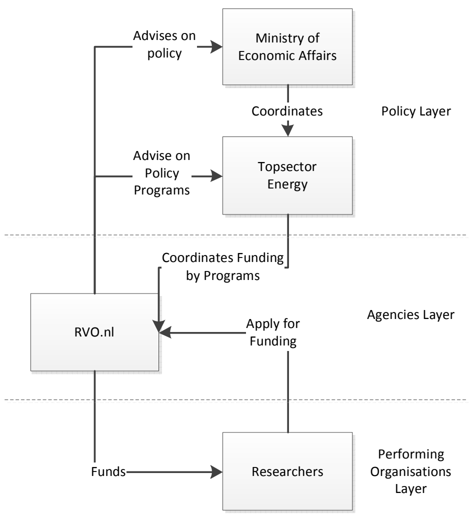
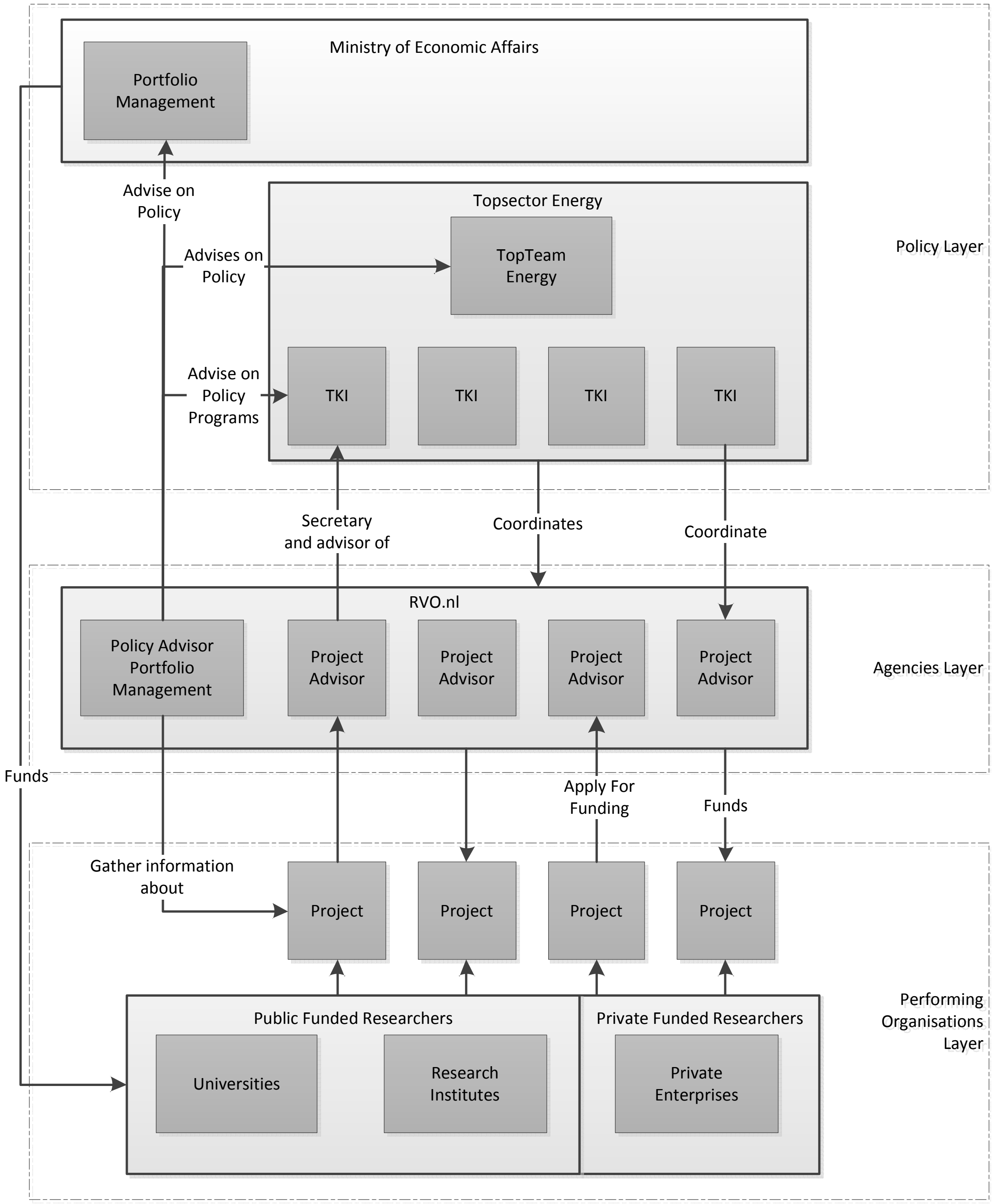



**Figure 19 Formal Map of Stakeholders regarding information flows based on Lepori's (2011) model of public funding layers (an extended version can be found in Appendix E).**


Ministry of Economic Affairs
Portfolio Management
Advise on Policy
Topsector Energy
TopTeam Energy
Advises on Policy
Advise on Policy Programs
TKI
TKI
TKI
TKI
Policy Layer
Secretary and advisor of
Coordinates
Coordinate
RVO.nl
Policy Advisor Portfolio Management
Project Advisor
Project Advisor
Project Advisor
Project Advisor
Agencies Layer
Funds
Apply For Funding
Funds
Gather information about
Project
Project
Project
Project
Public Funded Researchers
Universities
Research Institutes
Private Funded Researchers
Private Enterprises
Performing Organisations Layer