HyWays

SECOND PHASE OF THE PROJECT

TOOLBOX

(DELIVERABLE D3.24)

VERSION FINAL VERSION

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1 Introduction

HyWays[1] is an integrated project, co-funded by research institutes, industry and the European Commission (EC). HyWays aims to develop a validated and well-accepted roadmap for the introduction of hydrogen to the European energy system until 2030 and also provides an outlook to 2050. The roadmap will reflect real life conditions by considering technological as well as institutional, geographic and socio/economic barriers and opportunities at a country-specific level. Mobile and stationary applications are addressed including possible synergies between the two. HyWays is characterised by the novel approach of using extensive modelling to support strategic discussions between large groups of stakeholders from the HyWays Member States (Hy-MS), industry and institutes, and applying interdisciplinary models and tools.

HyWays comprises two phases of 18 months each. In the first phase, the introduction of hydrogen was analysed for six countries (France, Germany, Greece, Italy, the Netherlands, and Norway). In the second phase, the analysis will be carried out for another 4 countries, Finland, Poland, Spain and the UK.

HyWays has been structured in four work packages (WP). WP1 and WP2 identified relevant HyWays ;Member State-specific hydrogen energy chains as well as conducting a pathway analysis. WP3 went further and analysed the interaction of selected chains with the energy system, economy and environment as a whole for individual HyWays Member States. A high degree of involvement of HyWays Member State stakeholders was able to be achieved in the first and second phase due to several rounds of HyWays Member State and stakeholder workshops. WP 4 has the task of developing an EU roadmap as well as an EU action plan for the introduction of hydrogen based upon the analyses conducted in WP 1 to 3.

This report has the following structure. *Chapter two provides an overview of the main HyWays goals and the developed process with a description of the hybrid approach of transition analysis and modelling. Chapter three describes the HyWays approach (HyWays toolbox with modelling exercises, additional analysis, and workshops) in more detail.*

Further information on HyWays can be found on the HyWays website (http://www.hyways.de/).

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[1] A full description of the HyWays project with background documents can be found in [HyWays 2005].

2 Major goals of HyWays and HyWays process

As mentioned before, HyWays aims to develop a roadmap for the EU. The principal approach is first to develop HyWays Member State roadmaps and then formulate an EU roadmap based on these.

A qualitative description is made of the long-term state towards which the energy system will evolve. This includes the role of energy carriers like renewables and nuclear, the relevance of emerging technologies like carbon capture and sequestration as well as relevant application areas like private passenger transport or stationary applications for industry purposes.

In order to achieve this long-term vision, the transition of the existing system is structured by formulating a technical roadmap describing the penetration of hydrogen technologies (production, transport, distribution, storage and application) into the market over time and the market entrance of different applications. Further the second part of the roadmap contains socio-economic aspects like investment in infrastructure build-up, employment, GDP, and welfare impacts as well as emission developments of GHG and local pollutants.

Policy measures and key actions of relevant stakeholders that facilitate the introduction of hydrogen to the energy system are described in an action plan for the EU. The potential support from (improvement of) the existing policy framework (emission trading, feed-in tariffs) will be assessed as well as the introduction of new/additional policy instruments (e. g. clean air legislation, subsidies and taxation, specific support instruments for infrastructure build-up, etc).

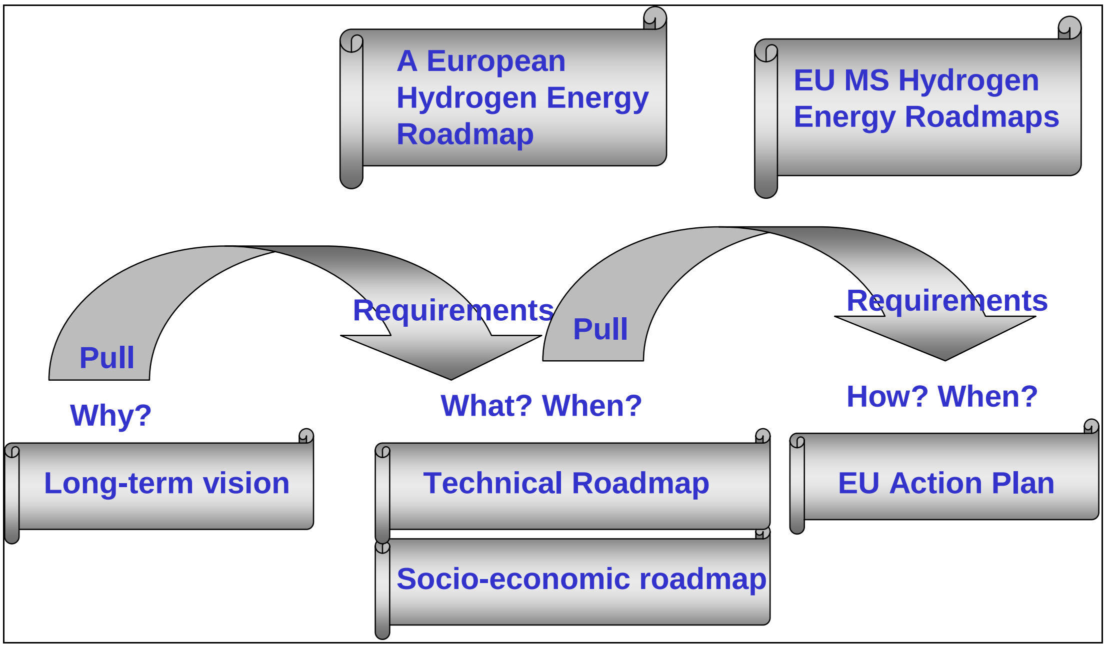


Figure 1: Objectives of the HyWays project

The implementation of advanced, highly innovative technologies such as hydrogen applications is not just a matter of achieving the right payback time. A transition towards a sustainable energy system involves changes on various levels. Therefore, the assessment framework includes the use of a well-balanced set of models addressing impacts on micro, meso and macro levels, an actor analysis as well as an analysis of a hydrogen infrastructure build-up. Validation workshops both within the consortium and with wider stakeholder groups in the participating countries play a crucial role in the HyWays process. The workshops serve as a platform to discuss and develop the methodology, collect the required input for the scientific analysis as well as for first order validation of the results. The national stakeholder workshops have two aims:

- To collect information on stakeholder preferences and other country-specific conditions. This information is used to modify the results of the scientific analysis in order to turn the 'optimal' pathways (from a strict techno-economic optimization point of view) into realistic pathways that reflect real life conditions.
- To validate the results of HyWays and to give these stakeholders a say in the process of selecting energy chains and developing realistic and preferable pathways, thus improving the quality as well as the acceptance of the HyWays results.

HyWays comprises two phases of 18 months each. In the first phase, the introduction of hydrogen was analysed for six countries (France, Germany, Greece, Italy, the Netherlands, and Norway). In the second phase, the analysis was carried out for another 4 countries, Finland, Poland, Spain and the UK).

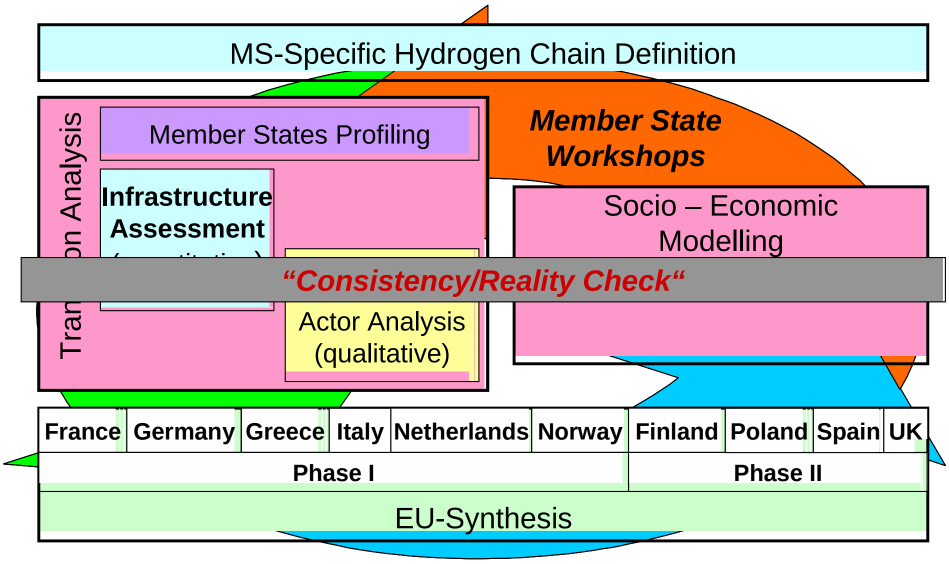
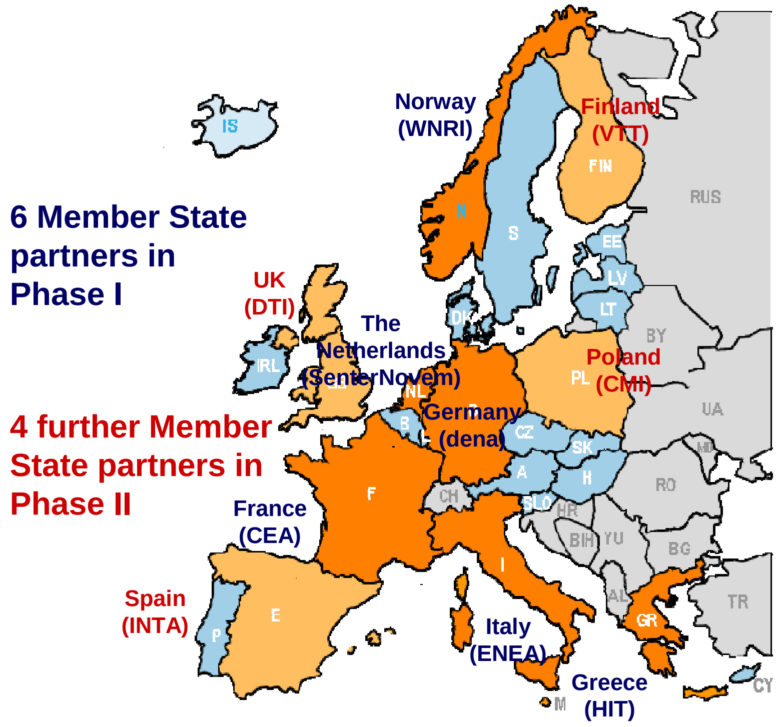


Figure 2: Conceptual information flows between transition analysis, modelling, and the EU-synthesis.



	Coverage [%] by	
	land area	population
Phase I	49.7	39.2
Phase I+II	80.5	71.4

Figure 3: Overview of Member States covered by HyWays

The socio-economic analysis (WP3) deals with the technical, economic and environmental aspects of integrating a hydrogen-based economy in regional markets. Based on the results of the Well-to-Wheel (WTW) and Source-to-User (STU) analyses (WP2 of HyWays), it studies the integration of complete hydrogen systems in the MS and European contexts. This includes hydrogen production, distribution, refuelling, storage and conversion in the existing energy and transport economy. It also analyses the potential impacts and ways forward at the techno-economic, social and environmental levels and the roles of industrial and other stakeholders in the transition.

The socio-economic assessment is based on a hybrid approach that combines quantitative and qualitative elements. The quantitative analysis of impacts is tackled by using computational energy system and economic models. Carried out in conjunction with the modelling work is a qualitative study based on past research in the field of transition analysis. The HyWays transition analysis is composed of two sections conducted in parallel: the infrastructure analysis and the actor analysis. The conceptual links between the components of the transition analysis and the computer modelling activities are shown in Figure 4, as well as the cross-cutting “reality check” in terms of MS workshops and stakeholder workshops that take place at various points throughout the study.

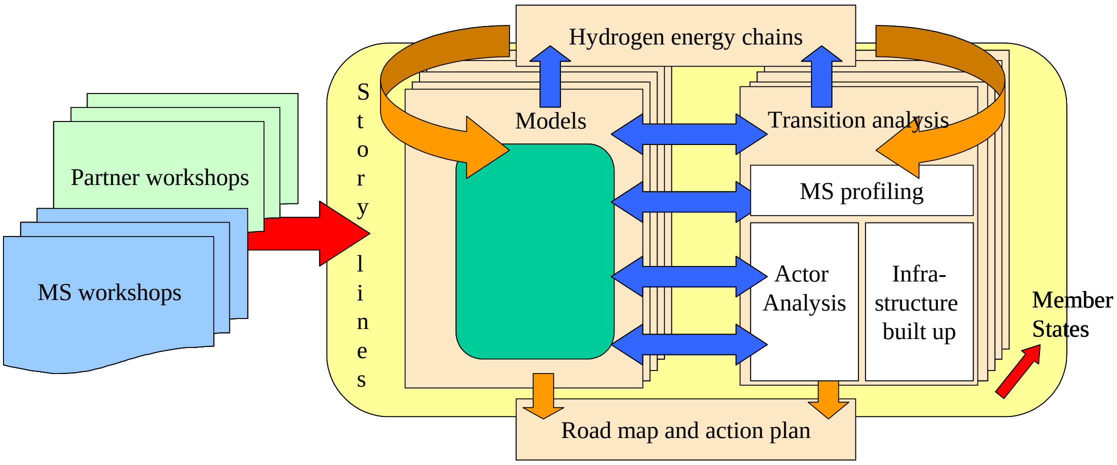


Figure 4: Conceptual information flows between transition analysis, modelling, and the EU-synthesis.

3 Methodological approach for the socio-economic analysis (Toolbox)

The following chapters describe the individual elements of the HyWays toolbox as well as the links between them. Very detailed descriptions of each element are available in the deliverable slist on the HyWays website.

3.1 Modelling activities

From the methodological point of view, different types of quantitative methods and models were used for the socio-economic analysis: E3 database, MARKAL, ISIS, PACE-T, and Copert. The infrastructure analysis (which is described in Chapter 3.2) is based partly on a quantitative modelling approach.

In a first step, hydrogen chains are analysed separately based on the E3 database. A complete hydrogen pathway analysis accounts for the entire pathway from feedstock preparation through hydrogen production (with and without carbon sequestration), conditioning (compression or liquefaction), to transport, storage, refuelling and hydrogen conversion in different application areas (a so called 'well-to-wheel' (WTW) analysis[2]) (see Fig. 4). The evaluation criteria are energy efficiency (primary energy demand (PED)), CO_2 emissions and costs.

In the next step, the most-promising pathways are included in the MARKAL model[3]. MARKAL belongs to the group of bottom-up engineering-based linear activity models which feature a large number of energy technologies and aim to capture the substitution of energy carriers at the primary and final energy levels, process substitution, process improvements (gross efficiency improvement, emission reduction), technology learning, spillover effects and energy savings. They are mostly used to compute the least-cost method of meeting a given demand for final energy or energy services subject to various system constraints such as exogenous emission reduction targets or prescribed energy technology paths (such as an administered phase-out of nuclear power or phase-in of green energy). These types of models can also handle the impacts of technology-specific policies (subsidies, standards) as well as provide information on the development of investment costs and cost-effectiveness.

In HyWays, MARKAL analyses are carried out to answer the questions:

- What would be the "best" (under given criteria like cost minimisation or emission reduction) use of limited resources (e. g. biomass use for heating, electricity production, industrial applications, bio fuels, or hydrogen?)?

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[2] For more background information about WTW analysis, see [Wietschel, Hasenauer 2006].

[3] For a model description, see [Seebregts et al. 2001].

- What would be the optimal design of the energy system with and without hydrogen?,
- What are the impacts of policies (like renewable targets or GHG reduction targets)?
- What are the impacts of hydrogen (e. g. on CO2 emissions and energy supply costs)?

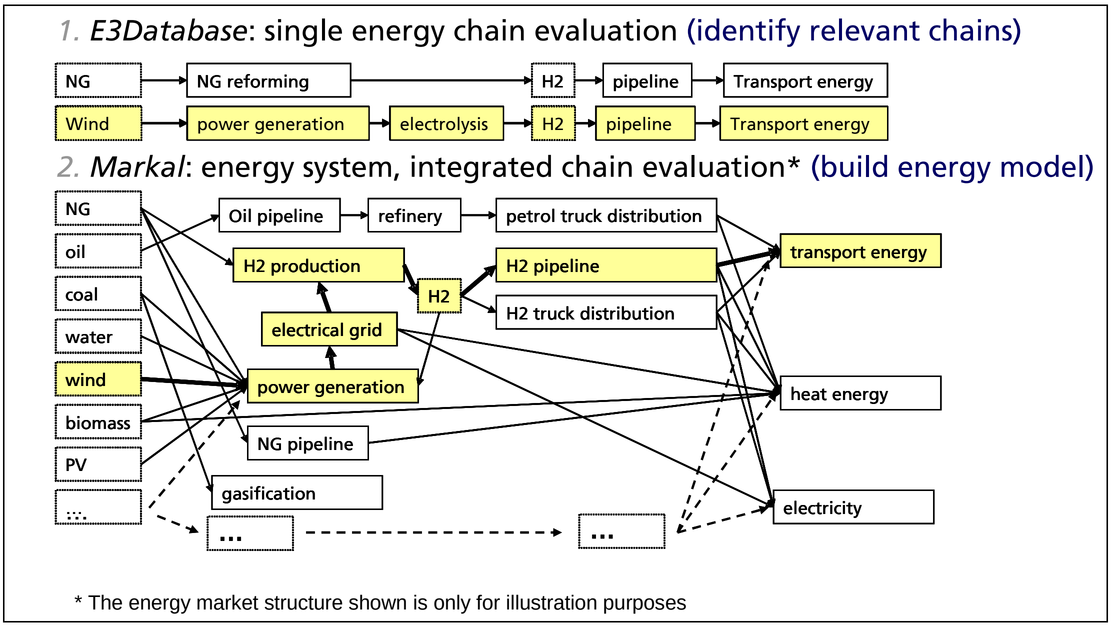

Figure 5: HyWays modelling methodology I

Normally, models like the E3 database and MARKAL are purely partial models of the energy sector, and do not interact with the rest of the economy. If, however, the subject of interest is the economy-wide results of energy policies, this partial analysis approach with bottom-up simulation, which does not account for the interaction between the energy system and the remaining economy, is less appropriate. Therefore the Markal results are integrated into the ISIS and PACE-T models for further macroeconomic evaluation. Data on production level, production structure, energy consumption and CO_2 emissions, which are an output of MARKAL, then become the input for the other models (see Fig. 6).

The ISIS and PACE-T models focus on an aggregate description of the overall economy and are general economic models with a rather rudimentary treatment of the energy system. Following the top-down approach, they describe the energy system (similar to the other sectors) in a highly aggregated way. PACE-T would be classified as a top-down model. The ISIS model could be classified as a hybrid model, bridging the gap between MARKAL and PACE-T. However, the ISIS and the PACE-T model both incorporate MARKAL bottom-up features while adopting different top-down settings.

A model often used to consider the effects of technological change is the Input/Output (I/O) model of the economy. Linking such a model to a detailed technology- and innovation-oriented scenario analysis as is done with the MARKAL-model creates an advanced modelling approach taking the relevant mechanisms into account. Furthermore, the results of innovation research on the export/import performance can be transformed into the effects on GDP and employment. Using the ISIS model[4], a meso-economic analysis on the basis of a micro-to-macro bridge can be carried out. ISIS (Integrated Sustainability Assessment System) is based on a static open multi-sectoral input-output model and can be used for the integrated sustainability assessment of technological strategies and measures.

While a dedicated PACE-T[5] approach offers substantial advantages vis-à-vis traditional purely top-down Computable General Equilibrium (CGE) models, it is still rather limited with respect to the representation of invention, innovation and diffusion of technologies at a very detailed sectoral level. This is where the ISIS-model, with its very high technological resolution of industries, provides a more detailed interface to bottom-up analysis when considering (endogenous) technological change. On the other hand, ISIS is set up as a static demand-driven input-output model that does not account for income flows of governments and bilateral international trade relationships. Thus, it is – unlike PACE-T – less suited to investigating the policy-relevant aspects of technological pathways such as fiscal impacts (revenue-recycling, potential double-dividend policies, crowding-out effects) and international spillovers (competitiveness issues).

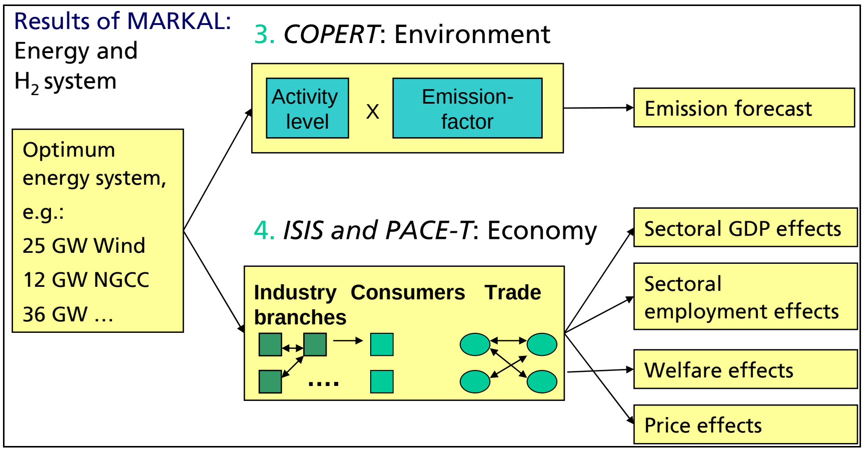

Figure 6: HyWays modelling methodology II

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[4] For a model description see [Walz, Nathani 2001].
[5] For a model description see [Böhringer et al. 2002].

The introduction of hydrogen technologies in mobile and stationary applications has the obvious advantage of reducing end-of-pipe emissions. At local level there are significant benefits for air quality, especially in urban areas, as the combustion of hydrogen in fuel cells does not result in any exhaust pollutant emissions, and in only a few emissions when used in an internal combustion engine (ICE). The emissions are calculated using the COPERT III model[6] as the road transport sector is the one where hydrogen has the largest deployment. Within COPERT, the vehicle fleet is modelled in detail and the effects on emissions of a market penetration of hydrogen vehicles can be quantified.

3.2 Infrastructure analysis

Besides modelling the energy system and socio-economic modelling, infrastructure analysis is one of the crucial tasks in the HyWays project. The essence of the infrastructure analysis task in HyWays is to create regional hydrogen demand and supply build-up scenarios over time taking into account the available resources as well as national policies and stakeholder interests. The purpose is to evaluate different infrastructure build-up options in economic terms and to derive recommendations for the introduction of hydrogen as a transportation fuel in the next decades

The economics and aspects of developing a hydrogen infrastructure have been studied by several groups for Europe[7] and on a country level[8]. The HyWays infrastructure analysis goes further than these, however, by studying the countries participating in HyWays individually based on country-specific inputs formulated by a wide group of stakeholders. The results thus provide insights into the situation of each specific country as well as, on an aggregated level, into a large part of Europe.

Figure7 shows an overview of how the different infrastructure analysis subtasks are organized. Inputs from other parts of the project or from the partners and stakeholders are shown on the left side, and the subtasks on the right. The tasks can basically be divided into demand and supply sides, where the hydrogen supply of each region is required to be in line with its demand. The subtasks will be described in the following section after a short introduction to the underlying key assumptions.

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[6] See [Ntziachristos, Samaras 2000]

[7] See [Tzimans, Castello, Peteves 2006]; [HyNet 2004]

[8] See [Ball, Wietschel, Rentz 2006]

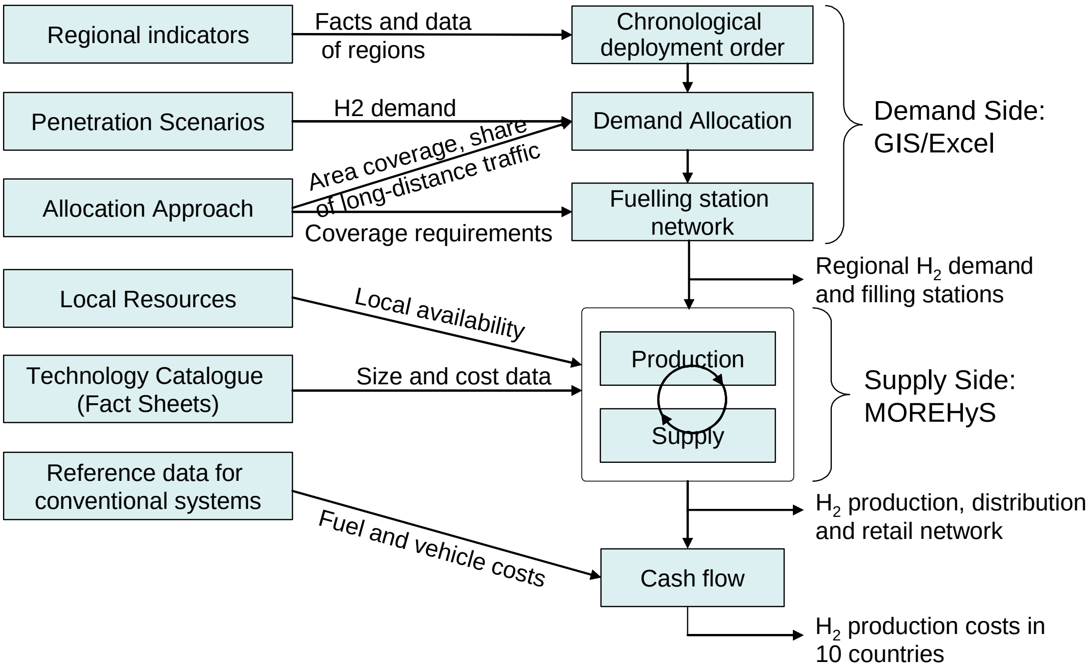

Figure 7: Overview of methodology

Calculating the hydrogen demand considers both long-distance and local traffic. It is assumed that demand for hydrogen builds up over time, starting in “early user centres” which are selected by the stakeholders and on long-distance roads which connect these. The regional deployment in subsequent phases is determined based on demographic indicators. Localised penetration curves for hydrogen vehicles underlie the calculation of hydrogen demand per supplied area and time. The number and size of fuelling stations per supplied area are calculated based on the existing number of fuelling stations and the hydrogen demand. The range of hydrogen vehicles is taken into account when allocating the network of hydrogen fuelling stations along roads.

The production and supply side were mainly analysed using the MOREHyS model (Model or Regional Hydrogen Supply), which is specially adapted to the needs of infrastructure build-up analysis.

MOREHyS[9] was developed by FhG ISI in cooperation with DFIU and is based on the open-source BALMOREL model (Baltic Model of Regional Energy Market Liberalisation), (see http://www.balmorel.com). MOREHyS is a technology-based (bottom-up), mixed-integer, linear optimization model with exogenous demand for electricity, heat and hydrogen. The model determines the minimal cost of production (as well as transport/transmission) and new

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[9] See [Ball, Wietschel, Rentz 2006]

investments under given constraints such as maximum emission levels or regional limitations for generation capacities and fuel availability which might affect the current energy mix. Possible interconnections with the conventional energy system concern CO2 emissions, the competition between hydrogen and electricity generation for renewables, the optimal load levelling of electrolysers or the co-production of hydrogen and electricity in IGCC plants.

The optimization variables of the model include the level of electricity, heat and hydrogen production per time period, technology type and area, investment in new generation capacity per technology type and area, electricity transmission and new investments in transmission capacities and the amount of hydrogen transported between and within all hydrogen areas. Hydrogen demand areas were defined based on NUTS areas. The MOREHyS model is coupled with a geographical information system (GIS) to handle geographical data (e. g. local feedstocks, demand centres) and to make specific analyses (e. g. route planning for hydrogen transport, fuelling station locations in an area).

The cash flow analysis compares the expenses for hydrogen production, supply (as calculated by MOREHyS) and vehicles with the savings made from replacing conventional fuel and conventional vehicles over time. The basic assumption for the cash flow analysis is that each hydrogen vehicle substitutes one conventional vehicle. The result is two cumulative cash flow graphs over time:

- The fuel cash flow shows the balance between the costs for hydrogen fuel provision and the savings for conventional gasoline and diesel fuel.
- The fleet cash flow graphs show the balance between investments in hydrogen vehicles and investment savings for conventional vehicles.

The cash flow graphs are scenario-specific, i. e. all the chosen assumptions about hydrogen costs, vehicle costs, penetration rates, fuel economy etc. are reflected in the results.

3.3 Actor Analysis

The primary goal of the actor analysis is to provide a systematic and qualitative assessment of aspects of transition analysis focusing on:

- The identification and description of key changes, which are the distinct changes necessary for the realization of the individual hydrogen chains chosen by each MS. These changes can be related to specific hydrogen chain components
- The identification of corresponding broad actor groups who might influence the realization or non-realization of the key changes

Actor analysis is the principal plank in the platform of the HyWays hybrid roadmapping approach. There is a raft of pertinent information which is vital to the quality of any roadmap but which is not easily captured by primarily numerical modelling approaches. Examples of such qualitative information include national policy priorities, social awareness and acceptance of hydrogen technologies, energy market characteristics, codes and standards and local planning considerations. The *ad hoc* treatment of such roadmap inputs in previous roadmapping efforts has adverse implications for the rigour and objectivity of the roadmap product and therefore also potentially on subsequent policy responses.

The Key Change Actor Mapping (KCAM) methodology, the practical application of actor analysis, was developed to strengthen the treatment of important non-numerical information in the hydrogen transition roadmapping process, and is used to support the main computational modelling components. The basic units in the KCAM methodology are "key changes", or distinct system development requirements. These are described, classified, and quantified by expert panels which not only ensures the high quality definition and evaluation of inputs but also enhances stakeholder consensus and ownership of the product. Although this requires securing stakeholder participation in the process, any potential difficulties associated with this are outweighed by the benefits of achieving genuinely negotiated positions in what is essentially a political endeavour. Without this level of active stakeholder involvement and validation, there is an increased risk of roadmapping products not ultimately being accepted by their intended recipients.

The KCAM approach is derived from a general systems development model and there are strong conceptual parallels between this and the compartmentalized hydrogen supply chain structure adopted by HyWays. This allows efficient data manipulation and comparison of results across a range of analysis vectors. A user-friendly Internet-based KCAM computer tool has been developed to allow users to conduct their own analyses of prospective hydrogen supply chains. Whilst the KCAM methodology has been developed specifically for HyWays, it was designed as a generic and stand-alone tool which could be used in other national contexts.

3.4 Modelling Toolbox overview

Figure 8 shows the output elements of the so-called HyWays modelling toolbox as well as an overview of the necessary inputs. The subsequent figure, Figure 9, illustrates the links between all methodological elements of HyWays.

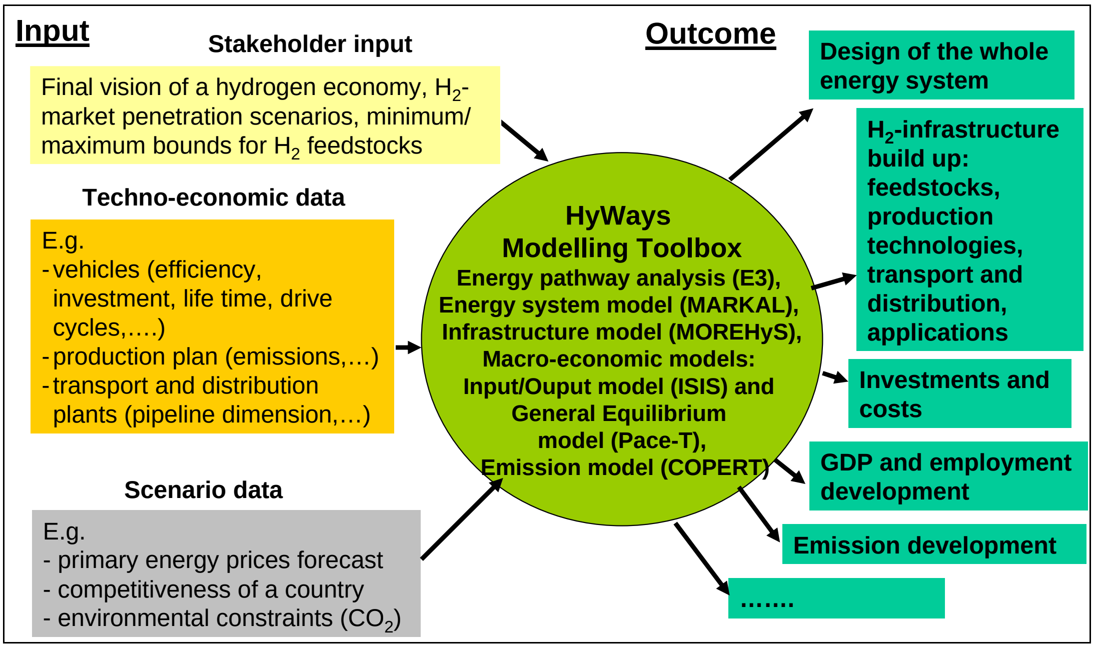

Figure 8: Input and output of the HyWays Modelling Toolbox

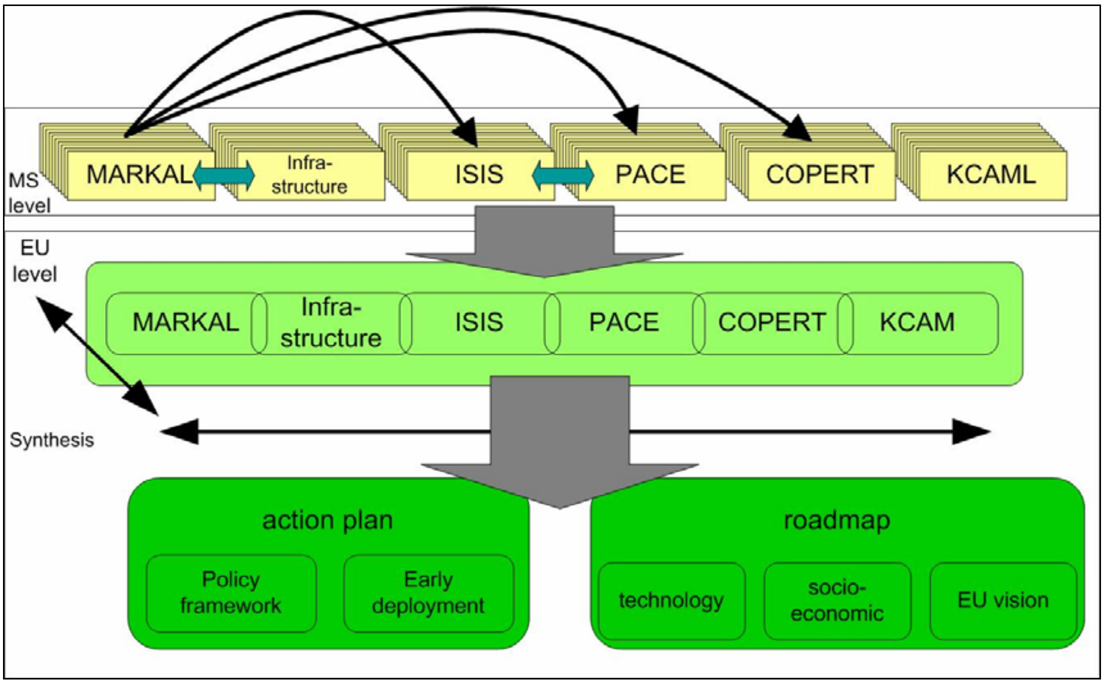

Figure 9: Model links and two level approach (Member State level and EU synthesis)

3.5 Role and organisation of workshops

As mentioned above, HyWays is not a purely model-based exercise. The role of the models is limited. The model analysis can provide some results, e. g. on the economic and environmental impacts of a given hydrogen penetration rate. However the crucial role of the Member States (MS) is to turn theoretical results (e. g. optimal hydrogen pathways) into well accepted and validated roadmaps taking into account the specific conditions which are beyond the possibilities of model analysis. The MS workshops (WS) thus represent an essential element in the HyWays approach.

Three MS-WS are foreseen:

1. In the first MS-WS, a basic vision of the country-specific characteristics of the future hydrogen energy system has to be developed (first long-term vision). This will provide the basis for the country-specific hydrogen energy chains.
2. In the second MS-WS, this (long-term) vision will be refined using the input generated by the assessment of the country-specific energy chains (second vision). In addition, first results of the modelling framework will be available as well as the regional profiling. The regional profiling will provide information about the characteristics of the current energy system but above all about the potential characteristics of the future energy system. In addition, the regional profiling will identify (country-specific) early markets for hydrogen that can enable the evolution towards mass markets.
3. In the concluding MS-WS, the final (long-term) vision for a hydrogen-based energy system will be established. It can then be assumed that this vision has been validated and accepted by the stakeholders. The basic inputs for discussion and final refinement of the second vision are the results of the modelling framework, the infrastructure analysis as well as the actor analysis. The discussions of the final validated and accepted vision will serve as input for the final model runs, ensuring that the model calculations, infrastructure build-up and actor analysis are all in line with the validated long-term vision of the future hydrogen system.

Figure 10 describes the overall approach (see also Figure 4). Some background information on workshop organization is given in Annex A.

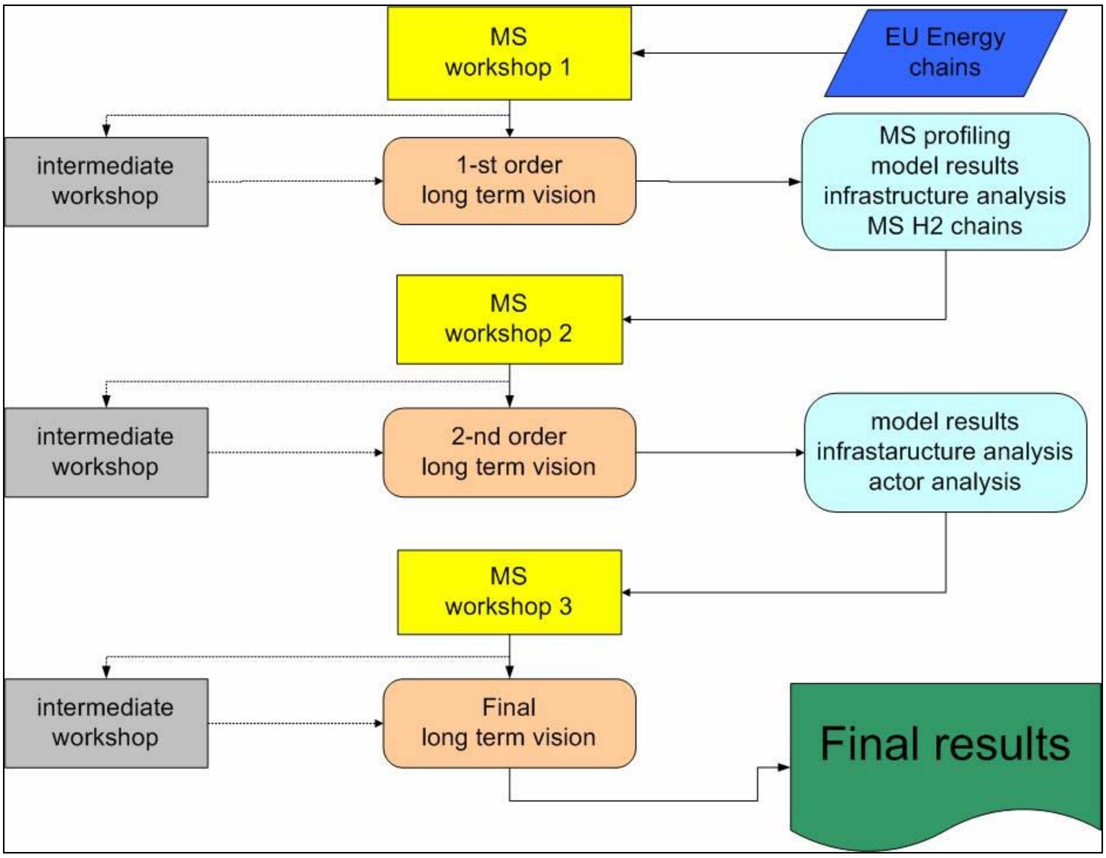

Figure 10: Member State workshop approach and model input

4 Annex A Guidelines with respect to the HyWays MS-workshops (process-oriented)

Preparation of the workshop:

- Participants. It is vital to the process to involve the right stakeholders because the validation at the MS level is an essential element in the HyWays road mapping process. A wide range of stakeholders needs to be invited. These range from representatives of various industry branches (energy production, distribution and retail etc.), NGOs, local (representing cities and/or regions) and national governments etc.
- Dissemination. It is advised to send around a number of HyWays flyers. A link to the website and the supporting background document should appear in the invitation to the stakeholders. Stakeholders will be better prepared for the workshop if they have previously studied these documents.

The workshop itself:

- Minimum progress requirements. The key issue is that appropriate progress is made and the required input to the HyWays process is generated (consensus building). It is up to the MS-representative to determine the structure of the workshop and find the best way to reach this consensus (how this is done may differ between countries). The HyWays consortium will provide the contents and advice, but will not prescribe the process. This is the responsibility of the MS-representative. If insufficient process is being made, additional workshops (or an alternative process which will yield the appropriate results and consensus) will have to be organized. International HyWays partners cannot attend these workshops.
- Harmonisation of presentations and HyWays input. Some topics may be handled quite easily by the MS-representatives (such as the discussion on the long-term energy system as well as the general introduction to the HyWays project). Other topics, such as the explanation of the energy chains (WtW, StU), might be more complex.
- Language. Again, it is up to the MS-representative to decide upon the approach likely to yield the most valuable results. Bear in mind that if the workshop is conducted in a language other than English, international partners (e.g. research insitutes) may not be able to follow the discussions and that their assistance and input might be very limited as a result.
- Topics are related. There is only a thin line separating the detailed development of the long-term vision of the energy system and the role for hydrogen and the selection of 6 to 8 MS-specific hydrogen energy chains. All these elements are interrelated. The long-term visions determine the hydrogen energy chains and these need to be in line with the vision

of the infrastructure build-up (evolving from the current state of the energy system to a future hydrogen-based one). If the discussion on the long-term vision goes well, the discussion on the selection of the MS specific energy chains might be rather quick. On the other hand, if it is difficult to reach a consensus on the long-term vision, the discussion of MS-specific hydrogen energy chains might prove to be an aid to reaching consensus on the long-term vision.

Input to the workshop

- A general powerpoint-presentation will be prepared introducing HyWays to the stakeholders and explaining the general process and the activities in more detail in the first MS-WS.
- The HyWays team supporting the development of the long-term vision (including the back casting - forecasting process) will provide a powerpoint-presentation with a number of basic questions for discussion with and among the stakeholders attending the MS-WS. These questions will address the long-term vision, the transition period (how to get from now to the desired future) as well as potential early markets.
- The HyWays team responsible for the energy chain selection (LBST, CEA, ECN) will provide specific information on results to be obtained during the workshop.
- The same holds for the team responsible for the infrastructure analysis (LBST, Fraunhofer-ISI).

After the workshop:

- The consensus on the issues discussed during the MS-WS need to be written down as a “first-order long term vision” (see also “indicators for progress”).

5 References

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Disclaimer

The results in this report are a reflection of a non-final stage of the HyWays project, with substantial stakeholder consultation still under way. Significant modifications are still due, and consequently none of the results given in this report should in any way be considered as final HyWays results.