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Strategic Roadmaps for participating countries

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Short Description
This document include country-specific political roadmaps, which are based on country-specific policy assessments and identified barriers and involves recommendations directed at political actors and energy planers.

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CONTENT

1. INTRODUCTION

The project DanuP-2-Gas aims to advance transnational energy planning by promoting generation and storage strategies for renewables in the Danube Region by coupling the electric power and gas sector. The effective realisation of this project depends strongly on the legal and regulatory framework. During the work within the WP3 the legal and regulatory status concerning the construction and operation of hubs for coupling the electricity and gas sector was assessed and existing national barriers have been identified.

These assessments are the basis for the development of country specific strategic roadmaps designed to foster energy storage through specific recommendations on different levels - for adjustments of the legal framework, reduce social, technical barriers as well as giving special insights on the potential of the sector coupling hubs in every country. Further, these roadmaps will be combined to a durable strategy to enhance sector coupling in the Danube Region.

In order to obtain valuable results for the roadmaps from the legal analysis and identified barriers, it is imperative to identify which measures and steps are necessary to achieve the EU and national targets for decarbonization, increasing the share of renewable energies as well as increasing energy security in the region. It must be emphasized that there are some barriers that apply to all countries, however country-specific challenges with corresponding national climate targets will play an important role for the developed roadmaps. The roadmaps will be discussed during national stakeholder workshops and individual expert interviews and additional adjustments, based on the interviews, will be incorporated.

Deliverable 3.2.1 serves as a basis for all the above-mentioned objectives. The aim of this Deliverable is therefore to define the needed actions to promote and deploy the sector-coupling hubs in Danube Region countries.

2. METHOD

The objective of this Deliverable is to present the developed country-specific roadmaps, which are developed based on the conducted legal assessment in every involved country and, especially, taking into account the identified barriers. In the development of the national roadmaps work package the core team met twice to discuss the aims, timeline and needed actions. The roadmaps, which than were developed by the respective project partners were disseminated to the important stakeholders/political/policy representatives in each country and gained feedback was incorporated into the roadmaps.

3. GENERAL APPROACH

A roadmap is a strategic plan that describes the steps needed to take to achieve stated outcomes and goals. It clearly outlines links among tasks and priorities for action in the near, medium and long term. A roadmap also includes metrics and milestones to allow regular tracking of progress towards the roadmap's ultimate goals. The IEA defines a technology roadmap as *"a dynamic set of technical, policy, legal, financial, market and organisational requirements identified by all stakeholders involved in its development."*[1]

The development of the roadmap in DanuP-2-Gas project relies on the general approach proposed by IEA in "Energy Technology Roadmaps. A guide to development and implementation", see Figure 1.

The results of analysis of biomass potentials, as well as infrastructural challenges made within the WP 2 are essential part of the roadmap, showing the existing situation with future scenarios. Evaluated use cases of sector coupling hubs within the WP2, highlight important findings for potential investors or other interested stakeholders, showing the possibilities and weaknesses of feasibility of such projects in every country.

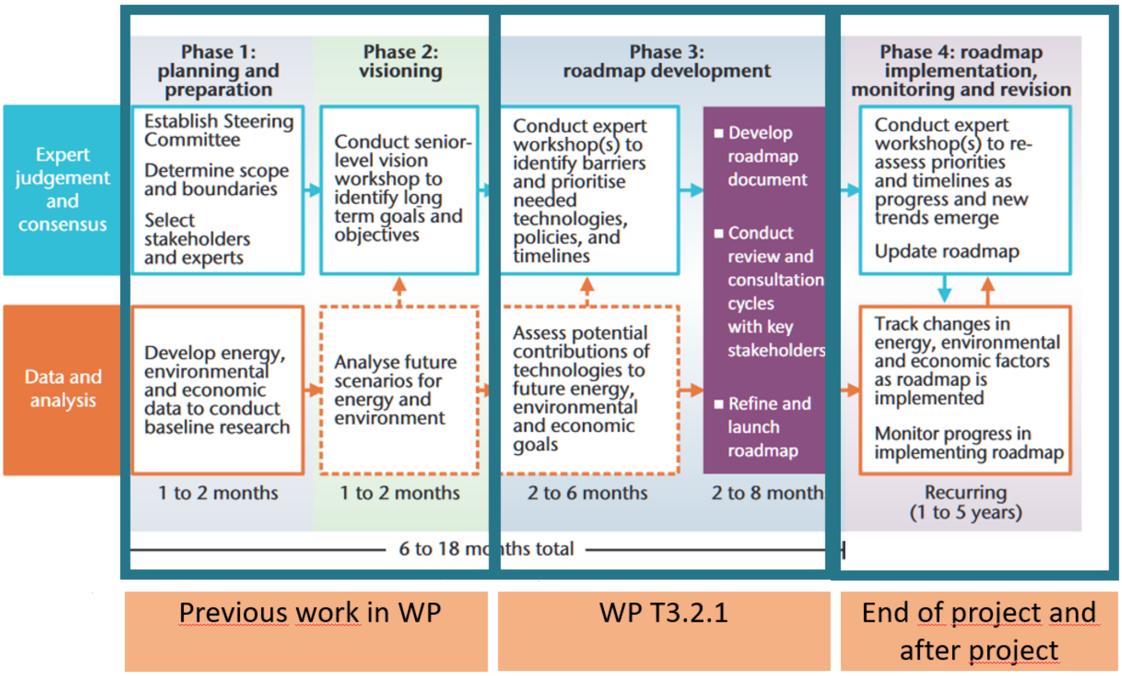

Figure 1. Roadmap process outline (Adjusted from IEA technology Roadmap Guide, 2014)

The analysis of the legal framework and identification of existing barriers is the core part of this roadmap. The further development of action items and needed steps to overcome the barriers, which are in line with the specific country goals, shows the step-wise plan to achieve the overall targets and aims of the roadmap.

[1] Energy Technology Roadmaps. A guide to development and implementation. IEA, 2014 Edition

4. THEMATIC SCOPE AND GOAL OF THE ROADMAP

The goal of the roadmap is to support the development towards increased energy security and efficiency in the Danube Region via storage of surplus renewable energy in the gas-grid and contribute to the EU climate-neutrality by 2050. The roadmap identifies needed actions to overcome existing barriers for wider implementation of sector-coupling hubs within the Danube region. The roadmap focuses foremost on adjustments of legal framework, however overall interdisciplinary barriers and challenges are shown and further steps identified.

5. CROATIA

5.1 NATIONAL (SPECIFIC) GOALS

- Before The Croatian Hydrogen Strategy until 2050 (Official Gazette no. 40/22) was adopted, the Croatian strategic framework had identified hydrogen and biogas (biomethane) associated with decarbonizing transport and heating sectors, but not as specific goals
- The Croatian Hydrogen Strategy emphasizes the advantages of developing the potential related to the hydrogen economy and is aligned with the goals of the European Hydrogen Strategy, as well as with the National Development Strategy of the Republic of Croatia until 2030
- 4 strategic goals have been recognized, namely: increasing the production of renewable hydrogen, increasing the utilization of RES potential for the production of renewable hydrogen, increasing the use of hydrogen, and encouraging the development of science, research and development of hydrogen technologies
- Integrated National Energy and Climate Plan for the Republic of Croatia for the period from 2021 to 2030
- The Energy Development Strategy of the Republic of Croatia until 2030 with a view to 2050 (Official Gazette no. 25/20) was adopted in February 2020 with one of the planned goals be to build around 2 500 MW of installed capacity by 2030
- The Strategy for Low-Carbon Development of the Republic of Croatia until 2030 with a view to 2050 (Official Gazette, No. 63/21)
- The Energy Development Strategy of the Republic of Croatia, like the Croatian Low-Carbon Strategy, foresees a reduction in greenhouse gas emissions of around 74 % in 2050 compared to 1990 emissions
- The Energy Development Strategy of the Republic of Croatia recognizes hydrogen as an alternative fuel and foresees its use in traffic in order to achieve the aforementioned objectives
- National Recovery and Resilience Plan 2021 — 2026: connect 1 500 MW of new RES electricity sources to the energy system by the end of 2024
- Climate neutral scenario of the Republic of Croatia non-energy sectors: Scenarios for reduction of emissions by sectors (%), compared to 1990:

Table 5.1.1 Reduction of emissions by sectors

	2018.	2030.	2040.	2050.
Energetics	- 24,3	- 43,7	- 67,8	- 95,6
Industrial processes and product use	- 44,5	- 68,0	- 73,3	- 87,7
Agriculture	- 38,5	- 45,6	- 56,6	- 67,0
Waste	93,9	14,8	- 35,3	- 61,2
Total	- 25,4	- 45,6	- 66,0	- 89,3

Table 5.1.2 Trends in hydrogen consumption and production under the climate neutrality scenario

Year	Total energy consumption* GWh/year	Share of hydrogen in total energy consumption %	Amount of hydrogen required kt/year	Electrolyser capacity MW
2020.	99.101	0,0	0,0	0
2025.	101.786	0,1	2,6	35
2030.	104.470	0,2	5,3	70
2035.	97.358	1,5	37	480
2040.	90.245	3,0	69	900
2045.	83.359	6,5	138	1800
2050.	76.473	11	214	2750

**Republic of Croatia, Ministry of Economy and Sustainable Development, Creation of Scenarios for achieving higher emission reduction by 2030 and climate neutrality in the Republic of Croatia by 2050 for the energy sector, Zagreb 28th September 2020*

However, given the growing potential of the hydrogen economy within the EU, as well as the potential expressed by Croatia with regard to RES, the above-mentioned objectives may be further increased as shown in Table 2b, which is a scenario of accelerated development of the hydrogen economy. Table 2b shows the required electrolyser capacity that obtain the electricity needed to produce hydrogen exclusively from RES ensuring renewable hydrogen. In view of the variability of RES, the RES capacity factor was set at 0,242 over the 30-year observation period.

Table 5.1.3 Trends in the consumption and production of renewable hydrogen in accordance with the climate neutrality scenario (potential scenario for accelerated development of hydrogen-based economy)

Year	Total energy consumption* GWh/year	Share of hydrogen in total energy consumption %	Amount of hydrogen required kt/year	Electrolyser capacity MW
2020.	99.436,50	0,0	0,0	0
2025.	101.762,50	1,25	13,94	384,02
2030.	104.468,80	3,75	46,20	1272,73
2035.	97.357,06	8,125	106,14	2923,97
2040.	90.245,30	12,50	172,60	4754,82
2045.	83.358,03	13,75	216,86	5974,10
2050.	76.470,74	15,00	266,03	7328,65

Yet, it needs to be considered that these goals and trends where determined before the current energy crisis, which requires their potential reconsideration. This should be done in accordance to existing situation on the EU-level and in extensive communication with stakeholders involved in every sector related to hydrogen and PtG implementation.

5.2 OVERVIEW OF POWER-TO-GAS RELATED ACTIVITIES

In Croatia currently, there is only one operational Power-to-Gas facility, and it has been commissioned mostly for academic purposes at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb (FAMENA). Croatian oil and gas company INA has in 2011 installed a hydrocracking facility as a modernisation action in one of their oil refineries, but this cannot be regarded as Power-to-Gas, due to the production of 'grey' hydrogen from natural gas.[9] However, it is worth mentioning that INA has several plans in including the 'green' hydrogen production in its refineries (Rijeka, Sisak) by 2025. Several other initiatives towards the introduction of novel technologies in this respect have been made in either academic or case studies. Moreover, Croatia has an initiative related to hydrogen and transport industry – a Croatia Mirai Challenge that occurs yearly and accompanies FAMENA and Toyota, with national promotion. This initiative has a goal, amongst others, to present the lack of utilisation of hydrogen in Croatia. There is no specific legal framework regarding Power-to-Gas technologies. One can only find a brief note of Power-to-Gas in the Croatian Energy strategy White book published in 2019 which served as a basis for the introduction of the Energy strategy until 2030 by the Croatian Parliament in February 2020.[10] Currently, active Law on renewable energy sources (RES) and efficient co-generation has no mention of utilising RES in this type of novel technologies. However, Croatian National Energy and Climate Plan (NECP) predicts the introduction of hydrogen in the transport sector, within 3.5%, by 2030.[11] This was challenged during 2020 by Croatian Chamber of Commerce, with a request to increase this percentage to min. of 0.5%. The NECP presents measures for co-financing projects that facilitate the acceptance and use of alternative fuels (hydrogen included) and a plan on establishing a hydrogen technology platform for research and application of hydrogen technology.12 In currently active Croatian laws and Rule books hydrogen is mentioned mainly in terms of a vehicular fuel (Rulebook on vehicle fueling stations, Rulebook on hydrogen powered vehicle homologation, Rulebook on vehicle technical inspection, etc.). Rulebook on granting emission units to facilities only mentions 'traditional' hydrogen production and utilisation. In the year 2020, two associations related to production and utilisation of hydrogen have been formed independently. The first one is the Croatian Hydrogen Association, closely related to the Power-to-Gas facility mentioned earlier which strives to promote and contribute to making better conditions for the introduction of hydrogen technologies as a key component for the development of clean and environmentally friendly industry and national economy. Currently, they list no active projects and initiatives. The second one is the Croatian Association for The Development and Application of Hydrogen Fuel Cells, which aims to gather both scientists and businesses, and has started promotion of their initiative 'Čisti vodik za Plavi Dunav i Zelenu Slavoniju' (Clean Hydrogen for the Blue Danube and Green Slavonia) with planned 44 MW of solar power used for hydrogen production. There has also been one pilot project idea of including the solar-powered hydrogen production facility (projected 60,8 kg/h). It has been planned to be a part of the Co-generation gas power plant in Peruća14 which has been abandoned as unfavorable to the environment in 2017. Following these efforts, the Croatian Chambre of Commerce and its Energy Association which operates within the Sector for Industry and Sustainable Development has adopted a new approach to speed up knowledge and information transfer on a national level by establishing Hydrogen group with the aim to gather all key players from industry, research institution, and public authority. The project proposal application process for Clean Hydrogen JU is underway. As part of that application, the planned 5 conceptual projects at the national level will be joined together.

5.3 SECTOR-COUPLING POTENTIAL IN CROATIA

For Identification of the potential for sector-coupling hubs for the particular country it is important to take into account the following: biomass potentials, availability and suitability of gas and power infrastructure and energy system specification.

The optimization tool, developed during the project was used to evaluate different use cases in all participating countries, the results gives robust overview of techno-economic feasibility of sector-coupling hubs. According to the findings respective recommendations for potential investors are provided.

5.3.1 BIOMASS POTENTIAL

Croatia's biomass sector strongly relies on the forestry and related industry. This is not likely to change, given the conservative approach of the Croatian industry. Almost 80% of Croatian forest area is state-owned which means that the distribution of the biomass is done through public procurement and auctioning system when the amounts of logs and residues are being distributed to processors after a public call. However, there are additional biomass sources available in significant amounts (such as crop residues).

In terms of residual biomass production Croatia scores quite well, compared to other smaller EU countries. 4.8 million tonnes per year of residues are produced, of which the main sources are cereals and oil crops. Only 1 million tonnes are known to be harvested at this moment (according to the Sankey diagram in Figure 1). Although a high percentage of these residuals can be mobilised, sustainability concept needs to be taken into account, of which the main is the conservation of organic carbon in the soil.

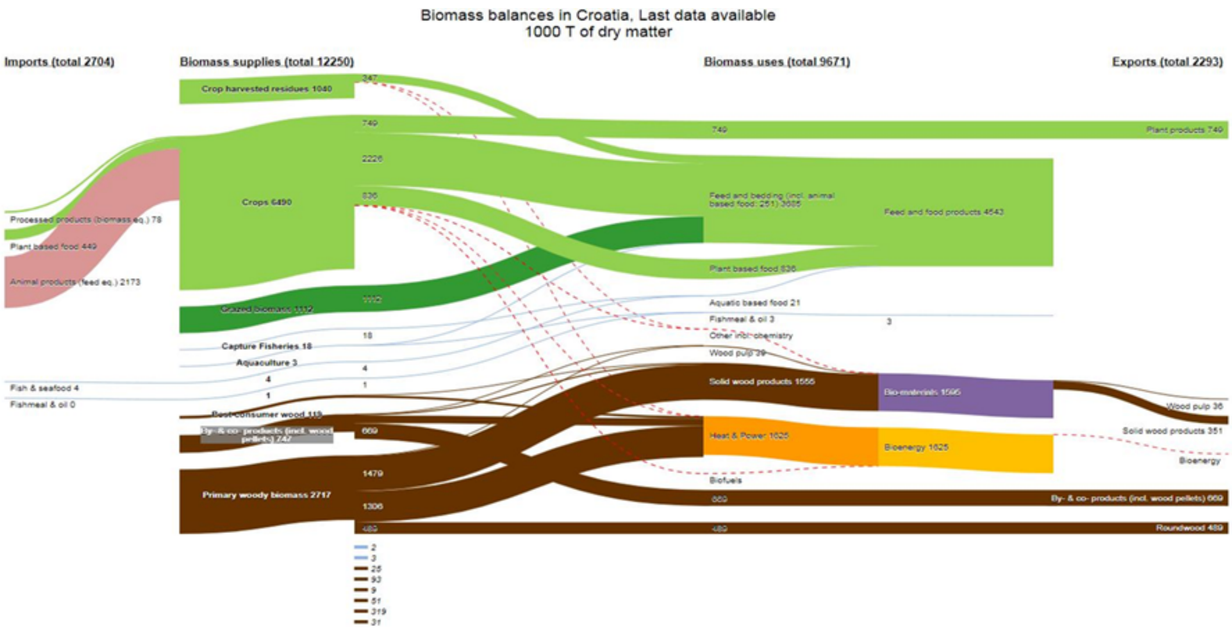

Figure 1. Biomass flows in Croatia (net trade), JRC Sanky Diagrams of biomass flows (P. Gurría Albusac, 2017)

Croatia has a relatively large cropping sector and therefore the residual biomass potential from crops are certainly of interest. By-products from arable crop production are mainly in a form of straw, stalk corn and corn cobs. They are used for traditional purposes (bedding) and lately, emerging agropellets for fuel and feed.

Amounts of crop residue identified in previous deliverables are not considered as a technical potential in the national biomass database, due to a simple reason – there are no specific collection points and collection should be handled directly between the provider and user. Introduction of larger sites which would serve as a trading and collection points (for both herbaceous and woody sources/residues) could enable wider use of this sourced in modern processes.

In terms of forestry and woody biomass, Croatia has a relatively large forest potential for the small size country it is. This results in a large primary and secondary forestry potential. Forests are considered as one of the most important resources for Croatian economy, both as energy source and feedstock for wood processing industry (Hulenić, 2020).

Table 5.3.1. Planned and achieved cut in period 2006-2015 and prescribed harvest for period 2016/2025 [11]

FMAP 2006 -2015	Prescribed harvest m^3	Achieved cut	% achieved	Prescribed harvest in 2016-2025 (m^3)	Prescribed harvest in 2016-2025 (tonnes d.m.)
Croatian forests Ltd.	57,935,018	53,639,369	93	64,196,393	36,881,791
Other legal bodies	661,366	128,463	19	525,372	301,834
Private forest owners*	7,047,369	2,392,543	34	15,649,957	8,991,135
Total period	65,643,753	56,160,375	86	80,371,722	46,174,760
Total annually	6,564,375	5,616,038	/	8,037,172	4,617,476

Many wood processing industries nowadays have adjacent cogeneration plants in which they utilise residues from their processes (e.g. sawdust). This has proved to be most convenient way to manage waste wood and to secure cheaper heat and power for industrial processes. The data in the national biomass database present publicly available information on the produced secondary biomass source from wood processing industries. Yet, the exact quantity of waste wood is unknown due to incomplete reporting to the Ministry of Environment and Energy by all wood processing companies (Hulenić, 2020).

Wood industry is a significant source of wood residues that can be used for energy production or other purposes. The availability will depend on production of main products and the pathways the wood residues take (e.g. feedstock for other material products). Wood residues from wood processing industry are for the most part already being used by the industry for own energy production needs or sold on the market.

Forest harvesting residues can also be collected. However, further assessments are needed to establish their location and the available amounts which can be recovered at acceptable costs and without harmful environmental effects.

Waste-sector biomass is not fully developed in terms of complete utilization of produced biomass – most of the waste produced still ends up in landfills. In order to satisfy the goals set for Croatia by the EU (maximum of 10% of municipal waste landfilled by 2035), the share of separately collected biodegradable waste types and biodegradable waste that should be energy and/or materially recovered will increase (e.g. collected biowaste should be above 40% by 2022).

The amount of produced sewage sludge in Croatia is around 35,000-40,000 tonnes per year (around 20,452 tonnes of dry sludge matter). Of that amount, around 50% of the sludge is produced by and located at the site of the Central Device for Wastewater Purification of the City of Zagreb. It is additionally estimated that, on a national level, around 1,100-2,000 tonnes of sludge are used for agricultural purposes and 110-200 are composted annually2. The remaining sludge is mostly landfilled.

Additionally, a large potential still remains in using aquatic biomass, with around 6,000 kilometres of Croatian seacoast. However, this potential is still untapped and not fully discovered, as research has only recently begun to examine it.

As a part of the project, a total of 150 potential sources of biomass have been located, majority being wood based sources, including pellet/briquet/chips producers (8), wood based industry residues (92) and logging (16). Other than that, there were two manure sources included in the final database, with 7 municipal/industrial organic waste sources and 24 sewage sludge sources. All potential sources are displayed on a map as shown in figure below.

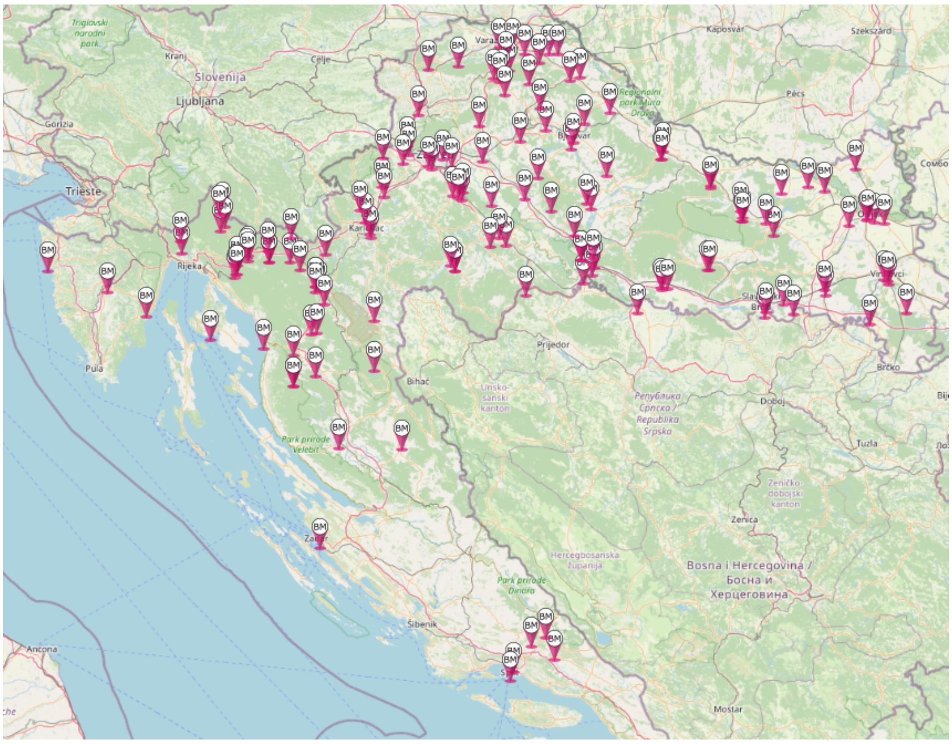

Figure 2. Allocated potential biomass sources in Croatia

[2] *CAEN, Management of sewage sludge from WWTPs when sludge is used in agriculture, 2010-2017*

5.3.2 DESCRIPTION OF CROATIAN INFRASTRUCTURE LANDSCAPE

In the recent years there has been some progress in renewable energy infrastructure installation. However, compared to other countries, Croatia still has much to improve. This is clearly visible in the case of harvesting the potential of solar energy. Despite its beneficial geographical location, Croatia is, in EU terms, only in front of Finland, Estonia, Ireland and Latvia, all of which have far worse conditions. Due to the lower installation costs, there has been some improvement in small photovoltaic installations (housing), but not so much on the larger scale. Wind energy has been harvested in higher extent, also with some new planned projects. Croatia has also traditionally relied on the hydroelectric powerplants, with some of the recent new project being held due to environmental concerns.

During the work on this project one of the tasks was to identify as many infrastructure points as possible, divided into various categories and connected through several criteria. The work resulted in allocation of 183 renewable plants (biomass, wind, hydro and PV), 8 industrial plants, 184 connection points (mostly electrical with some for natural gas), 14 transport hubs and 28 international links (again, mostly electrical). Recent electricity and gas prices variations provide a challenge in long-term planning of complex and large systems relying on both sources, but the overall composition of the infrastructure databases show a great potential of using the information for obtaining the quality assessments regarding new P2G investments.

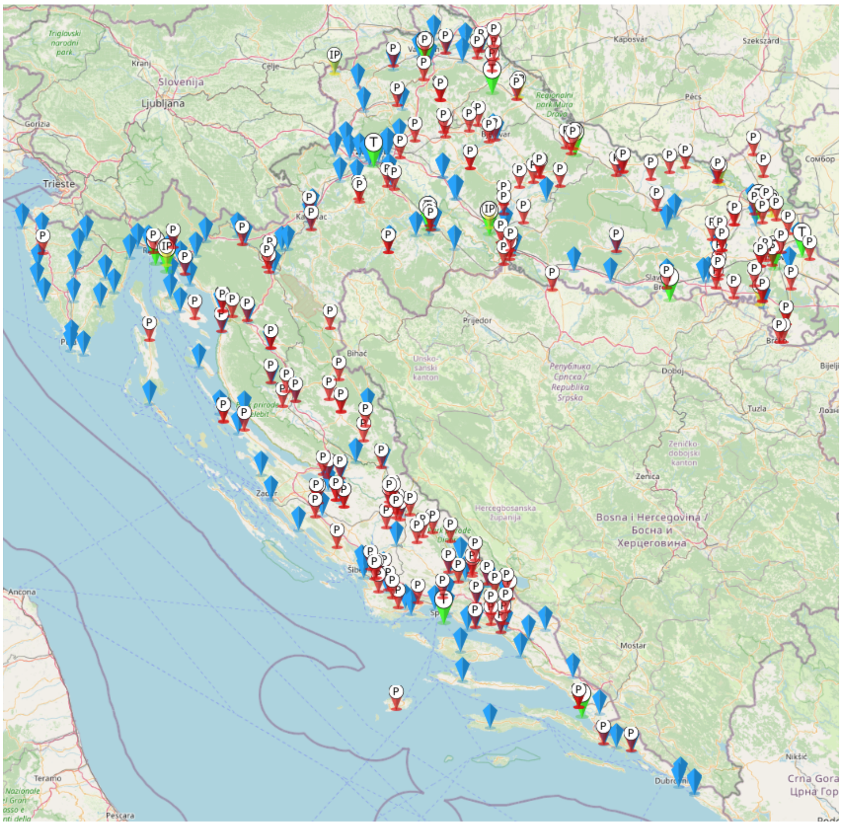

Figure 3. Allocated infrastructure points of interest (P - renawable plant, IP - industrial pant, T - transport hub, blue diamond – connection point)

5.3.3 USE CASE ANALYSIS

Wokpackage T2 in this project was dedicated to using a developed optimization tool to run several case studies against the data collected as described in the previous chapters.

In case of Croatia, three locations for potential P2G investment were considered. The first one is industrial plant Petrokemija Kutina (noted as IP), which is the largest petrochemical industry in Croatia with large consumption of natural gas. The second is TUČ (noted as REP), which is a factory that has a photovoltaic plant within their facilities. Advantage of TUČ is its own biowaste which is an opportunity for P2G. The third one is a greenfield location (noted as GF) in Karlovac-Dubovac since there is a possibility to connect both to the electricity and gas networks nearby. For each one of casestudies, variations of methane prices and subsidies were considered finally ending in the total of 12 optimization cases listed below in Table 5.3.2. Every solution from Table 5.3.2 is obtained using the simulation period of one complete year.

Table 5.3.2. Simulation cases

	Conservative prices of methane			Higher prices of methane		
	No increase IP	No increase REP	No increase GF	10x increase IP	10x increase REP	10x increase GF
No subsidy	CHP & biochar	CHP & biochar	CHP & biochar	Continuous production of biomethane in winter, damped in summer	Continuous production of biomethane in winter, intermittent in summer	Periodic production of biomethane (only in winter)
50 % subsidy	CHP & biochar	CHP & biochar	CHP & biochar	Periodic production	Continuous production	Continuous production

Maximum allowed return on investment period of 20 years was considered uniformly in all cases, however often the optimum economical setup of the investment yields much shorter return on investment periods. The results, discussed in detail in the respective project deliverable, showed that in scenarios with current gas prices in Croatia, biomethane production is not economically feasible. On the other hand, optimization tool showed that in all 3 cases (IP, REP and GF) combined heat and power plant is profitable with current electricity and gas prices. Increase of methane price enables investment in biomethane production within the P2G where hubs next to IP produce biomethane throughout the year while hubs next to REP and GF hubs produce methane mostly during winter when gas prices are much higher. With an additional increase in the gas price, production would become profitable throughout the year.

5.3.4 EXISTING FUNDING POSSIBILITIES

Within the DanuP2Gas project and efforts invested in Workpackage 4 aimed at finding appropriate funding mechanisms and possibilities which could provide financial support for new P2G projects and investments.

In the case of Croatia, five calls were identified which could be applied to the project scope, including general calls for research and development for cross-sector projects or proofs of concept, specific calls for e.g. electricity generation and/or consumption, agricultural scoped, etc.

Funding opportunities usually, upon granting, ensure at least 40-50% of co-financing of eligible costs, going up to the full coverage of costs (for R&D projects for research organizations).

Unlike other collected data, this is, of course, prone to more frequent changes which require continuous monitoring. Based on the current development strategy it can be expected more incentives towards projects related both to hydrogen and P2G technologies.

5.4 EXISTING BARRIERS

In the following chapter existing barriers and needed actions for the deployment of P2G projects in Austria are listed.

Legal barriers

- In the energy laws, it is necessary, especially for connection to the network in terms of defining connection and network fees, to define more precisely which of category a P2G facility belongs (the Electricity Market Act differentiates between customers, supply, production, distribution, transmission and storage of energy). The article describing energy storage says: »energy storage facility as a facility which stores electrical energy by converting it into another form of energy, meaning reversible hydroelectric power plants, pumped hydroelectric power plants, electrical boilers with storage, heat pumps, batteries, electrolyzes with hydrogen storage and other devices which can store electric energy in a form, and deliver it to the transmission or the distribution grid later“. However, the definition of energy storage in the law, taken from the EU Directive 2019/944 on the common rules for the internal market for electricity defines: »deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy and the subsequent reconversion of such energy into electrical energy or for use as another energy carrier«. According to the first definition, a P2G plant that does not use the produced gas for reconversion to electrical energy is considered an active consumer and not energy storage, but according to the second definition, a P2G plant that sends the gas into the gas system is also considered an energy storage facility. The classification of P2G plants is important as storage facilities have to pay the lesser connection fee, but on the other hand, have to obtain energy permit which adds another step to the grid connection process.
- In the energy laws (Network codes of HEP DSO and HOPS, Rules of Connection to electricity and gas distribution and transmission network, etc.) it is necessary to clearly define the possibility of connecting P2G plants to the energy infrastructure (electricity and gas network).

- P2G technology is recognized in the Energy Development Strategy of the Republic of Croatia, but it is insufficiently integrated into the energy system and the promotion of energy security, independence, and impact on the environment.
- The administrative part after projecting and before the connection and start of operation of RES usually requires many administrative procedures involving stakeholders from different areas which are time-consuming.
- Often changes of law can have a negative impact on the administrative procedure in the long-term process of project development and thus the need to finish or change the existing project.
- In the case of technologies with intensive development, including P2G, a long administrative procedure can cause a need for changes in planning and decisions to change technology, which can bring the project and needed permits to the start or additionally extend the administrative procedure.
- The spatial development strategy of the Republic of Croatia foresees the creation of guidelines for the choice of locations and planning of wind farms, solar plants, and small hydro plants, and based on that a document called „Analysis of spatial capacities and conditions for the use of renewable energy sources potential in the Republic of Croatia“. This document does not include an analysis of the potential of using P2G technology.
- Difficulty in connecting RES to the electrical network due to the network characteristics, eg. the unfavorable form of network (due to the form of Croatia's territory the transmission grid is mainly radial or meshed through neighboring countries), the problematic spatial distribution of RES, the age of the network and change of network user structure.
- The spatial plans of lower-level territorial units in the Republic of Croatia are often not aligned, especially considering the spatial classification of land use, so getting the needed permits and documents for the development of the RES project, and also future P2G facilities is more difficult.
- Uneven approach of including locations into spatial plans of certain counties considering the size of RES facilities (power plants of power of 20 MW and more are defined as energy buildings of state importance, power plants of power between 10 MW and 20 MW are defined as buildings of regional importance, but for the spatial plans of some counties different rules are used.
- The appropriate legal and regulatory framework including funding possibilities for the construction of P2G projects is still in development, which may hinder faster deployment.
- The act on thermal treatment of waste (NN 75/2016) does cover waste streams foreseen in this project, but P2G plant/technology is not mentioned as well as the usage of mentioned feedstock for hydrogen production, thus the implementation of P2G in case of this feedstock is not viable at the moment.

Socio-technical barriers

- Lack of communication between the private and public sectors (industry and legislative/strategic framework)
- Knowledge gap on P2G and hydrogen topics, and their implementation

- A big variety of stakeholders should be involved in the implementation of P2G projects thus higher complexity in achieving sufficient acceptance for construction may occur.
- Low awareness of climate change and knowledge of clean technologies e.g. P2G, concentrated knowledge exists in a small group of energy experts and industries.
- Local projects may face resistance from the local community. However, promotion for local, community-based projects is very important on the one hand to technically and economically try out different approaches in real operation and on the other hand to create demand.
- Complex and long permission procedures, also because of the insufficient knowledge level of public authorities involved.

Techno-economic barriers

- Lack of appropriate infrastructure for hydrogen use in mobility and for injection into the gas grid.
- Readiness of gas infrastructure for higher shares of hydrogen should be proved as well as the amount of investment needed for adjustments of the infrastructure should be identified.
- P2G business cases are often non-competitive. However, from the national economy point of view, projects for the generation, distribution, and use of green gases as well as the maintenance of existing infrastructure have positive effects on GDP, jobs, import reduction, etc. Therefore, a stronger focus on these positive effects should be used to gain additional/alternative funding and to increase public acceptance.
- The P2G process is not yet fully technologically mature; there is a need for more demonstration projects. As well as constant market observation and targeted networking with demonstration projects can ensure that we remain technologically "up-to-date". Innovations should be anticipated as soon as possible.
- High production costs of domestic green gas from P2G applications. However, the system service function (being able to create load balancing in the electricity grid and offering seasonal storage options for wind and PV) can be used nationally and thus long-term support can be argued for. This is an important reason to develop P2G projects nationally because, through the import of green hydrogen from abroad, no possibility for nationally necessary system services will be available.
- As high investments for the projects are needed, the examination of whether projects can be designed in a modular way so that investments or generation capacities can be adapted to the increasing demand over time should be made.
- In order to decrease additional losses in case of gas storage and later conversion into electricity requires P2G plants to be located near existing RES. The availability of additional space and profitability of building such plants near existing or planned RES due to the RES locations or in the case of RES parks must be considered.
- In case of injection of the produced gas from the P2G facility into the gas infrastructure, it is recommended to build P2G plants near the gas infrastructure, under the condition that the existing gas infrastructure has the technical ability for hydrogen transport. Due to poorly branched gas infrastructure in Croatia and the lack of gas infrastructure in areas with the greatest P2G plant

potential (e.g. wind farms in the coastal part of Croatia, especially Lika, Dalmatia, and Dubrovnik area), there is a reduced potential for building P2G plants.

5.5 ACTION ITEMS AND RECOMMENDATIONS

Taking into account the identified existing barriers, a variety of action items and needed steps, which should be taken to overcome this gaps and barriers and to achieve the goals of the roadmap, are summarised in this chapter.

Action items needed to overcome legal barriers

- The existing legal framework concerning P2G and hydrogen should be more detailed and precise in determining goals and action plans
- Further development of supportive legal framework for electricity (e.g. EES, …), waste management and heating sectors to implement faster uptake of P2G hubs and sector-coupling
- Development of legal framework to support the uptake of hydrogen utilization and production
- Change of the existing legislation in order to more precisely define P2G facilities and technology and their inclusion into the electrical and gas system
- Reducing the number of unnecessary administrative procedures by merging multiple steps into one or decreasing the needed documentation by connecting the same information from multiple sources (state or local institutions)
- Depending on the importance of P2G technology, a system of incentives or another measures have to be made for the production and/or storage of hydrogen and subsequent reconversion into electrical energy has to be implemented in order to make the technology more profitable in the early stages, which would additionally encourage and accelerate further development of P2G technologies.
- Interministerial groups targeted to implementation of new technology outputs
- Action plans that integrate hydrogen and power-to-gas with specific case scenarios
- Inclusion of identified key stakeholders in the decision-making process

Action items needed to overcome socio-technical barriers

- Organization of public engagement events, to increase the acceptance levels of the general public
- Development of specific financing mechanisms for better public involvement in the renewable energy production
- Capacity building and proactive approach of key stakeholders (assistance from national associations and public institutions)

- Definition of social-techno-economic framework within PPP on hydrogen and P2G topics

Action items needed to overcome techno-economic barriers

- Further development of financing mechanisms for demonstration projects
- Intensified funding options for roll-out and commercialization of the respective technologies
- Intensified support for R&D projects
- Uptake and transferability of knowledge and experience from EU-level stakeholders
- While planning the electrical grid development and planning and connection of RES to the electrical grid, especially in the part of the grid where there are problems with the offtake of electrical energy from RES in certain time periods, the potential of building P2G plants in the vicinity has to be considered
- Recognizing the benefits of the use of P2G plants in combination with RES, especially in parts where the electrical grid is not sufficient for new RES connection or if there is a need for storing the surplus of produced electrical energy and its use in periods of peak consumption

Further action items and recommendations

- The cooperation between investors, governments, and public authorities should be intensified in order to foster the development of new projects
- In terms of just and inclusive transition, immediate steps in research are required with emphasis on the integration of hydrogen and P2G
- In order to achieve decarbonization goals through the utilization of hydrogen and P2G hubs immediate steps are required to move forward from BAU. This can be obtained through specific steps, focusing mainly on the legislative framework, where public stakeholders cooperate intensively with the private sector. Additional knowledge transfer is required, with the industry as a lead. This is only possible with a fast implementation of the Action plan developed on the national level which should be delivered by joint cooperation of the public and private sectors.

LIST OF ABBREVIATIONS

IP	Industrial plant
GF	Greenfield location
R&D	Research and development
GHG	Greenhouse gas
OG	Official Gazette
P2G	Power-to-Gas
RES	Renewable energy sources

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Ordinance on licenses for performing energy activities and keeping a register of issued and revoked licenses for performing energy activities (OG 88/15, 114/15, 66/18)

Regulation on the establishment of a system of guarantee of origin of electricity (OG 84/13, 20/14, 108/15, 55/19)

Regulation on encouraging electricity production from renewable energy sources and high efficiency cogenerations (OG 116/18)