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The facilitation of small hydropower in Switzerland: shaping the institutional framework

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Abstract

The paper aims to contribute towards further shaping of the institutional framework in Switzerland in order to facilitate the development of small hydropower (<10MW). The context of the research is the current liberalisation process of the electricity sector, the forthcoming electricity gap and the government's aim to increase the weight of renewable energy sources (RES), as well as post-Kyoto regulation. Small hydropower (SHP) has, generally, a higher energy ratio and lower production costs than other RES, and should therefore be further facilitated. In addition, decentralised and small-scale pump-storage schemes can contribute to further integrated stochastic RES production and the regulation of the grid. In 2008, SHP produced 5.4 % of the Swiss electricity production. The potential is only partially tapped and current estimates show that the use of this potential could be increased by 60-100 %. The technology is well developed and several mechanisms within the institutional framework already exist to facilitate SHP (e.g. newly introduced feed-in tariffs scheme) although further evolution of the institutional side is needed. Based on the literature of co-evolution between technologies and institutions, and based on the coherence framework, ideas are developed of how to improve the institutional framework.

Firstly, the dynamics of the electricity sector have to be considered such as the trend of decentralisation and the need of additional storage capacities to absorb within the infrastructure the stochastic electricity production. Climate policies influence the electricity sector as well and more coherence between energy and climate policies is needed.

Secondly, the application of the coherence framework to the SHP case shows that institutions have to be coherent in size and scope with the technology. More standardisation is required to reduce transaction costs. On the technical side, standards could contribute to a technical standardisation of SHP thus improving the quality of the implementation of the technology. This is necessary as with the liberalisation new actors have entered the market without always having all the needed competencies. Furthermore, the idea of including pump-storage power plants below 10 MW within the institutional framework which facilitates SHP is developed. The deployment of such plants could be boosted within multipurpose infrastructure and the rehabilitation of existing plants.

It is therefore mainly the institutions which have to further evolve to be better aligned with the well developed SHP technology, and which have to include new ideas such as SHP pump-storage schemes. This will lead to further deploy RES and contribute to climate change mitigation.

1. Introduction

In Switzerland, alongside neighbouring countries, there will be an **electricity gap** between the domestic production and demand around 2020-2025 [1, 2]. This is because the nuclear power plants within Switzerland are reaching their end of use, the long term purchase contracts of electricity with France are coming to an end, and there remains an increasing demand for electricity. Therefore, the Swiss government aims to increase the total amount of electricity produced by **renewable energy sources** (RES) between 2010 and 2020 from 16 to 24% [3, p. 6]. One of the seven measures of this initiative is the facilitation[1] of hydropower, including small hydropower (SHP) [4].

The increase of RES generated electricity will not fill the coming electricity gap in Switzerland and electricity producers will need to increase their production with large power plants (e.g., new nuclear plants, combined cycle gas thermal plants) alongside better energy efficiency and frugalness. Gas thermal plants will not be operational before 2013 (i.e. post-Kyoto context) and are only politically feasible if adequate ecological provisions, such as CO_2-compensations, are taken into account. The compensation scheme is still a topic of debate in the national parliament. The applications for new nuclear plant are in process, but there remain significant obstacles such as the political acceptance in the population.

The European and the Swiss electricity sectors are presently undergoing a **liberalisation process**, which focuses on institutional changes, such as deregulation, reregulation, unbundling, introduction of competition at the production level and other measures related to the market structure. This process favours the development of decentralised and small-scale power production, which requires less investment and is perceived as being less risky [5, p. 235]. SHP is one possible technology to assure such production.

Small hydropower is part of the electricity infrastructure which is a network industry. **Network industries** have high asset specificity and provide essential services. They are very complex technical, economical, and political systems. Failures within the network have significant and large scale consequences. The liberalisation process within network industries pursues the aim to increase the economic and systemic efficiency as well as the quality of the service. Due to this process, the institutional framework has changed from a public utility-oriented system towards a market-oriented system even though electricity is still seen as an essential service. The technological side has changed much less.

In the electricity sector competition occurs at the production, access and sales levels. Transport and distribution remain monopolies and are strictly regulated. SHP has to compete with the other energy sources. At the sales level SHP competes for example with other RES on the green electricity market. Certain electricity suppliers offer the possibility of purchasing an electricity mix from RES (e.g., through labelled “naturemade” electricity). If more end users demand green electricity from RES sources, this will contribute to the facilitation of these technologies. Currently only the big electricity consumers (above 100 MWh/year) can choose their supplier and few suppliers offer to all the customers (i.e. also private customers at household level) the option of labelled RES electricity. The second phase of the Swiss liberalisation scheduled for 2014 will lead to open the market to all consumers.

In Switzerland, there is large heterogeneity of ownership among the electricity production firms, most of them still belonging to public entities, such as communes and cantons. These public entities make decisions on the institutional framework which causes them to be shareholders and decision makers at the same time.

The liberalisation process and the government’s aim to increase the weight of RES are opportunities for SHP. However, there are also threats from climate change including the disruption of water supplies, the administrative barriers and there still remains considerable environmental opposition. On a worldwide scale, SHP is certainly one possible way of enabling people to have electricity and therefore to assist in reaching the Millennium Development Goals.

The **aim of this paper** is to further develop the institutional framework which facilitates the development of small hydropower in Switzerland. Similar developments could be adapted to other countries. The paper is part of the ongoing PhD research of the author. The final results of the PhD thesis will be available at the beginning of 2012.

This paper is structured as follows: Section 2 gives an overview of the small hydropower situation in Switzerland. Section 3 gives a brief summary on the framework of coherence between institutions and technologies on which the research is based. Section 4 gives the analysis based on the framework and, finally, Section 5 provides concluding thoughts and recommendations for further research.

2. Small hydropower in Switzerland

Small hydropower plants combine the advantages of hydropower with those of decentralised power generation. The **definition** used in this paper corresponds to the International Energy Agency [6] and the Swiss facilitation regulation for RES: Small hydropower is below 10 MW. The considered lower limit is around 200 kW. Such a fixed value definition, which is used for incentive mechanisms, could lead to the design of smaller plants which receive

[1] Facilitation is defined as the *“act of assisting or making easier the progress or improvement of something” (*http://wordnetweb.princeton.edu/perl/webwn?s=facilitation).

incentives instead of designing one or several bigger plants which are technically and ecologically the optimal solution for a given site.

In the early 20th century, there were nearly 7'000 small-scale hydropower plants in Switzerland of which more than 90% were rated below 300 kW and consisted of water wheels and mini turbines [7]. Table 1 highlights figures during the 20th century when the number of operated MHP plants below 300 kW strongly decreased. **History** shows that SHP is a very developed technology and received a lot of technical R&D in Switzerland during previous decades through government facilitation programs (e.g., PACER, DIANE) and research laboratories (e.g. MHyLab, EPFL-LCH). In 2008, SHP represented 9.9% of the Swiss hydropower production and 5.4% of the total electricity production (see Table 2).

Installed electrical capacity (kW)	**1914**		**1947**		**1973**		**1985**	
	Plants	**MW**	**Plants**	**MW**	**Plants**	**MW**	**Plants**	**MW**
Below 300	~6'700	85	~5'700	85	~1'900	50	~700	46
301 - 1'000	87	46	116	68	126	72	127	74
1'001 - 10'000	67	229	102	407	139	518	147	550
Above 10'000	14	290	65	2'300	163	10'040	171	11'780
Total till 10'000	**~6'854**	**360**	**~5'920**	**560**	**~2'165**	**640**	**980**	**670**
Total hydropower	**~6'870**	**650**	**~6'085**	**2'860**	**~2'330**	**10'680**	**~1'150**	**12'450**

Table 1: Small-scale hydropower in Switzerland during the 20th century [7]

Installed electrical capacity (kW)	**2008**				
	Plants	MW	GWh / year	Total electricity production from hydro-power	Total electricity production
Below 300	700	56	250	0.7%	0.4%
301 - 1'000	171	97	510	1.5%	0.8%
1'001 - 10'000	172	641	2'725	7.7%	4.2%
Above 10'000	167	12'538	31'744	90.1%	48.8%
Total till 10'000	**1'043**	**794**	**3'485**	**9.9%**	**5.4%**
Total hydropower	**1'210**	**13'332**	**35'229**	**100.0%**	**54.2%**

Table 2: Small-scale hydropower in Switzerland in 2008 [8]

The last in depth study of the SHP **potential** done by EGES goes back to 1987 [9]. The technical hydropower potential in Switzerland below 10 MW was evaluated around 9'000 GWh/a, whereby approximately 3'000 GWh/a were actually used. In November 2008, the Swiss government initiated a new study with WaterGisWeb AG on the evaluation of the remaining technical potential of SHP in Switzerland. The final results will be available in 2012. After initial estimates, and with the adequate institutional framework, the author of this paper evaluates that the use of the SHP potential could be increased by 60 to 100% (2'150-3'450 GWh/a more) until 2030 [10-12].

SHP has a high **energy payback ratio**[2]. For example run-off-river hydropower has an energy payback ratio of 30 to 267; biomass 3-27; wind power 5-39; solar photovoltaic 1-14 [13]. The payback ratios do vary significantly for

[2] For each power generation system, the "energy payback" is the ratio of energy produced during its normal life span, divided by the energy required to build, maintain and fuel the generation equipment. If a system has a low payback ratio, much energy is required to build and maintain it and this energy is likely to produce major environmental impacts.

renewable energies due to variable site conditions (e.g., topography and hydrology in the case of hydropower, quality and quantity of the wind in case of wind power, intensity of solar radiation for solar power).

Another main advantage beside the high energy payback ratio is that SHP has, on average, lower **production costs** (including financial costs) compared to other RES. They are at 10-25 cts/kWh, wind power at 20 cts/kWh, biomass at 28-42 cts/kWh and solar above 60 cts/kWh[3] [1, Fig. 3.2-3].

Within the existing **institutional framework** in Switzerland several mechanisms concerning the facilitation of SHP exists. The most important one is the feed-in tariffs scheme (KEV/RPC) introduced in 2009[4]. It is a cost-effective net metering [Energy Law, 14, Art. 7a]. The tariffs depend on the installed capacity, head and a bonus linked to the hydraulic construction. It varies between 5 - 39.5 cts/kWh. The tariff is guaranteed for 25 years and there are no ecological constraints to it. It cannot be combined with the labelled green electricity market. The pool to fund the feed-in tariff (FIT) is limited and its income is provided by 0.4-0.6 cts per consumed kWh. It is a consumer based mechanism and not a state subsidy. The pool has been quickly emptied resulting in a lack of financing for new SHP plants. The introduction of the FIT was a significant step towards the facilitation of RES, but it lacked certain provisions such as limited funding and, in the case of SHP, it could have been better adapted to either low head schemes or continually maintained and rehabilitated plants [15]. In addition, there are certain lacks in the application procedures (more plants announced than technical feasible), payments delays and the VAT was added without further consultation of the different stakeholders. The administrative procedure costs, especially around the required certification, are, in relative terms, significant for small SHP projects. The national parliament is currently reviewing the feed-in tariffs scheme.

Other mechanisms are the labelled green electricity schemes (TÜV and Naturemade[5]) and the water rental, which is a tax of 80 CHF/kW for hydropower above 2 MW installed capacity. For SHP it starts at 1 MW with 0 CHF/kW and increases linear to reach 80 CHF/kW at 2 MW. Furthermore, the federal government supports SHP with its facilitation programs ("EnegieSuisse" till 2010 and "EnergieSuisse after 2010") and contributions to the feasibility studies for SHP below 1 MW. And finally, as a typical feature of a federalist state, there are additional mechanisms at cantonal level[6], which are not uniform for the whole country and therefore the institutional framework varies between Cantons.

To further use the untapped SHP potential, the institutional framework must evolve further as the technology is already well developed. Multipurpose plants, such as combined with potable and waste water networks, and rehabilitation of existing plants require a special attention, which they partly receive already. An additional option is to use SHP for energy storage as developed further below in the paper.

3. The coherence framework

The conceptual framework for the research and analysis is the framework of coherence between institutions and technologies. The broader theoretical background is the literature on the co-evolution between institutions and technologies in the case of network industries and New Institutional Economics (NIE), in particular Transaction Costs Economics. An approach based on this literature and framework is relevant as SHP is part of the electricity sector, which is a network industry.

North defines **institutions** as *"the rules of the game in a society or, more formally, the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social, or economic. Institutional change shapes the way societies evolve through time and hence is the key to understanding historical change."* [16, p.3]

Saviotti [17, p. 12] defines **technology** as *"the set of activities by means of which human beings modify their external environment."* These "activities" mostly refer to technical artefacts and do not include ideas. Within the research of this thesis, small hydropower represents the technology. Being part of the electricity infrastructure, specificities of the latter have to be taken into account (e.g., continuous and instant adjusting of demand and supply).

Co-evolution is the reciprocal interactions between two populations, entities or systems. These interactions have a significant causal impact on each other and need to be strong and in localised proximity [18]. The literature of co-evolution between institutions and technologies describes the general process of changes within them and highlights

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[3] The cost per kWh in the case of solar power are decreasing significantly each year, but still generally considerably higher than hydropower.
[4] Before 2009 another kind of feed-in tariff scheme was in place with only two feed-in tariffs of 15 and 16 cts/kWh.
[5] Price premium between 3.2 – 8.6 cts/kWh (Jan 2010). Electricity market price around 10 cts/kWh.
[6] E.g., Canton Bern: MHP plant below 300kW: no concession taxes of 0.015 ct/kWh + loans without interest

the necessity to align these changes [5, 19, 20]. It does not provide a framework to measure and compare institutions and technologies nor measure the impact of the changes. Neither does it explain how governments could facilitate such an alignment. The framework of coherence between institutions and technologies tries to overcome this problem in the case of network industries.

This framework aims to measure the degree of **coherence** between institutions and technologies thus leading to a measure of the performance of the network industry. As developed by Künneke, Finger, Groenewegen and Menard, it contains a way to compare and match institutions to technologies [5, 19-23]. The framework offers a static analysis and is conditioned by the fact that it applies to networks or technical systems and not the individual products so often described in theories of co-evolution. Taking into account the **system relevant functions** (interoperability, interconnection, capacity management and system management), the coherence between technology and institutions increases if both are aligned on a similar level within their organisational structure, scope of control and coordination mechanisms (Figure 1).

Performance in this framework is defined by way of three parameters: the economical performance, the public value and the integrity of the technical system [19, Ch. 2.3]. The economical performance concerns the static, dynamic and system efficiency. The public value is defined by the quality, accessibility, affordability and reliability of the service, as well as the environmental aspects. Performance criteria of the technical system integrity include resilience and robustness.

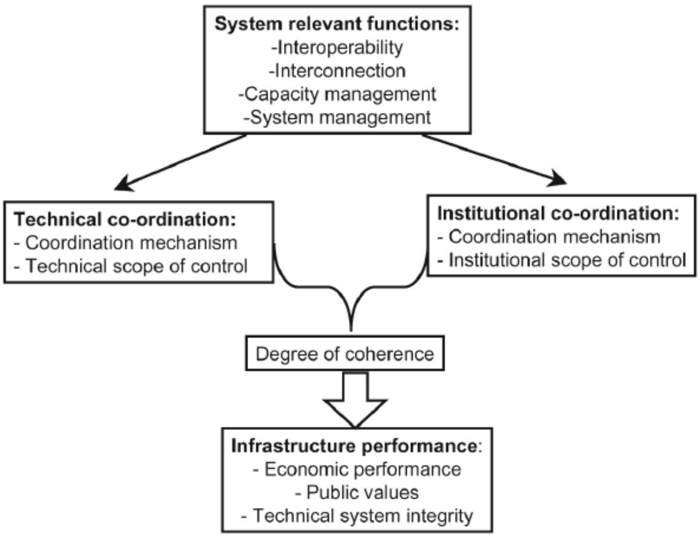

Figure 1: The framework of coherence between institutions and technologies [19]

The literature on this framework highlights the need of alignment between institutions and technologies when changes are made to the infrastructure. It does not yet provide a roadmap of implementation.

As an example, in the electricity sector the liberalisation brings an institutional change because of the unbundling of the vertical and centralised structure. If the technological side does not change and remains centralised and vertically intergraded, the coherence between institutions and technologies decreases and therefore the performance of the infrastructure will decline. The smart-grid developments show that the technological side is changing to ensure the coherence by unbundling technically the grid. At the same time, technology has to be supported by suitable institutional frameworks in order to perform, which leads to this co-evolution between institutions and technologies.

4. Analysis

The coherence of the electricity sector will be analysed before focusing on the coherence of SHP. The coherence for individual institutional mechanisms such as the feed-in tariffs, labelled electricity, CO_2-credits has already been analysed in depth in [24].

4.1 Coherence framework applied to the electricity sector

As mentioned above, the institutional changes generated by the liberalisation process lead to more decentralised and small-scale electricity production; a technological change. This development encourages smart-grid innovation processes to allow a better integration of the decentralised production units, thus ensuring coherence.

Pollitt identifies five scenarios for the electricity network in 2050 in the case of Great Britain [25], which can also be applied to other countries such as Switzerland. One of the two main scenarios is micro-grid networks in which the consumers are the centre of activity within the network. The operational management of the network occurs in a decentralised way and is based on smart grids.

An additional driver which reinforces this decentralisation is the growing importance of cities in energy and climate policies. About 70% of the world's primary energy consumption arises from cities [26]. One main initiative at city level is the Covenant of Mayors initiated by the European Commission [27]. Already around 1500 local authorities commit to move beyond the EU 20-20-20 objectives in terms of reduction in CO_2 emissions through enhanced energy efficiency and cleaner energy production and use. Seven Swiss cities have already signed[7] this initiative (April 2010). In addition, several large Swiss cities intend to step out from nuclear power and causing the importance of alternative generation options such as RES to increase. Cities may develop their own institutional mechanisms to facilitate RES.

The facilitation of RES as another main institutional change also favours decentralised electricity production because RES must be built where the renewable source exists and are in the Swiss case mostly small-scale. The facilitation of wind and solar power leads to more stochastic electricity production. Taking the system relevant functions of capacity and system management of the electricity infrastructure (see Section 3.), more storage capacity are required to ensure that the infrastructure can deal with this additional stochastic production. SHP pump-storage schemes could offer such a decentralised storage option.

Furthermore, the institutional changes linked to climate change lead to CO_2-compensation if gas thermal plants are built in Switzerland. The current Swiss compensation scheme does not allow use of RES, except biomass, for CO_2-compensations [28]. Evolution of the institutions is therefore required. The compensation scheme is currently in debate in the national parliament, including the amount of compensation which can be made with projects abroad. Ideas include the introduction of a CO_2-tax to partly fund the feed-in tariffs (instead of increasing the amount paid by the customers per kWh) or the inclusion of other RES such as SHP in the Swiss Emission Trading Scheme (ETS). In case of the latter, negotiation started this year between Switzerland and the EU to merge the two ETS. It must be noted that the post-Kyoto regulation is still vague, but technology transfer was a key topic at the Copenhagen conference and mechanisms such as the Clean Development Mechanisms (CDM) could contribute to export the Swiss SHP technology and import Certified Emission Reductions (CER) to compensate for CO_2-emissions of gas thermal plants.

Finally, the introduction of more hybrid and electrical cars will require more electricity generation. RES generation could be facilitated with an additional CO_2-tax on fossil fuel to trigger this development.

4.2 Coherence framework applied to the SHP case

The SHP technology is well developed and mature [13]. This does not mean that no new technological innovations are required (e.g. increase the environmental integration, increase lifetime of turbine, better part-flow / variable speed turbines, etc.). Such innovations are generated today mainly by new environmental constraints which are considered as institutions within this research. The alignment between institutions and technologies in the case of SHP leans more towards the institutional side, which must further evolve to facilitate SHP, i.e. be aligned with small-scale, decentralised and RES electricity production (which can in some cases include storage capacities). The size of institutions has to be coherent with the size of the technology.

The coherence in terms of the technical and institutional scope of control needs to be increased. For example, the feed-in tariffs are regulated at national level, whereas concession procedures are at cantonal or even communal level, and differ between the cantons. More useful for small-scale electricity production are institutional procedures at a "small-scale" level with smaller transaction costs. A decision must be made as to whether feed-in tariffs are allocated in a decentralised way (also in view of smart-grids) or cantonal procedures are harmonised to have a nationwide procedures for SHP. A greater level of standardisation and streamlining of procedures is needed to reduce transaction costs (e.g., combine concession and construction procedures, simplified procedures for

[7] See http://www.eumayors.eu/covenant_cities/list_en.htm?cc=ch

rehabilitation projects). The other option is to increase the size of projects, i.e. have a group of SHP projects within the same sub-basin zone and do all the procedures in once for the whole group.

Beside institutional standardisation, there is also technical standardisation. With the introduction of the feed-in tariffs and the liberalisation, a considerable number of new actors (engineering companies, construction companies, suppliers of equipment, etc.) have entered the market, of which some do not have the competencies to design, rehabilitate and/or construct a SHP plant. This reduces the technical quality and therefore the productivity of the plant. The standardisation could be in form of a technical quality label which guarantees certain technical minimum standards for a SHP plant (e.g., standard for the overall efficiency of the plant from the water intake till the connection to the grid, or standards on the water intake, penstock, turbine, electromechanical part, etc.)[8]. The label could be used as an “energy label” at the production level, complementing the existing energy label at consumption level (e.g., fridge, washing machine). Environmental consideration would be taken into account as well. Thanks to improved quality, the labelling costs could be recovered by lower breakdown risk which reduces financial losses. This quality label could be linked with the feed-in tariffs or the concession allocation for all new and rehabilitation projects.

As mentioned in Section 4.1, more storage capacities are required within the electricity infrastructure. In 2009, there were 2 SHP pump-storage plants and 18 SHP storage plants in Switzerland [30]. SHP plants with storage facilities would not only contribute to the balancing of the electricity grid and generation of peak electricity production, but also to the regulation of rivers after extreme climatic events, which will increase due to climate change. Such schemes could be used for surface water (including rehabilitation of existing plants) and in multipurpose infrastructure, for example also for power balancing in potable water networks where the local authority is in charge of the water and electricity supply. Potable water networks in mountain areas have the technical potential for pump-storage between reservoirs. Networks which have been designed to cover peak demand during the tourism season offer the opportunity of hydropower pump-storage during off-tourism time. In a similar way, artificial snow making infrastructures with reservoirs, of which more and more will be built due to global warming, could be used during summer for pump-storage. There may also be a small technical potential within operative and inoperative galleries around big dams (e.g., former discharge galleries). The increase in quality of weather forecasts[9] will improve coordination between solar and wind electricity production and the management of SHP storage facilities. The Canton of Bern states in its latest water strategy that it wants to improve pump-storage scheme on existing plants [31]. The institutional framework needs to be adapted to include the facilitation of SHP pump-storage scheme (e.g., feed-in tariffs offering more remuneration for peak hour production, decentralised capacity payments, dynamic residual flow over the day). With the alternative project of the Swiss parliament in opposition to the initiative “Eau vivante” an amount of 0.1 cts/kWh is budgeted for a better ecological adjustment of pump-storage scheme. Finally, with the development of variable speed pump-turbines for big hydropower, opportunities will arise for small-scale implementation. This would be an example of co-evolution on the technological side.

5. Conclusion

As SHP has a higher energy payback ratio, lower production costs than other RES, and can be combined within multipurpose infrastructure and contain storage capacities, it should be further facilitated. Based on the co-evolution literature and the coherence framework the analysis has developed ideas to improve the institutional framework which shall lead to the increased use of the SHP potential. This research will contribute to substantiate the coherence framework, which is currently very qualitative and conceptual, and lead to recommendations for the alignment between institutions and technology. The ideas include 1) institutional and technical standardisation and aiming for coherent scope between institutions and technology to reduce transactions costs, 2) the shaping of the institutional framework for SHP pump-storage development, and 3) a better linkage between CO_2-compensation policies and RES facilitation. Further research is necessary to assess the SHP pump-storage potential in Switzerland and to develop the institutional and technical standardisation.

The results of the research shall contribute to the review of the feed-in tariffs scheme (ongoing), the post-Kyoto framework (2013-2020), the revision of the Energy Law (forthcoming) and institutional changes on cantonal level. One aspect to investigate further is the infrastructure dynamics, i.e. how the overall evolution of the electricity infrastructure affects SHP development. One example of this is the option of decentralised and small-scale pump-storage. The research shall contribute to determining to which degree institutions need to be decentralised or centralised.

[8] A first list of standards has been developed by [29]

[9] http://www.meteocentrale.ch/en/current-weather-switzerland.html or http://www.immergenugstrom.ch/videos/energiewetter

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