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Original article

Evaluation and recommendation of a subsidy instrument for new large hydropower plants, use case of Switzerland

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ABSTRACT

Hydropower is the central pillar of the current Swiss electricity mix. The Swiss energy transition will profoundly change the electricity mix by transitioning a third of electricity generation from nuclear towards renewable energy sources mainly. This backbone role of hydropower is hindered by the current Europe-wide sluggish economic situation, characterized by subsidized new renewables energies which distort electricity prices, a partially liberalized market and power production overcapacity. In this difficult context, a strong and comprehensive political support through long-term policy will be of utmost importance to accompany hydropower across this transformation. This article explores various subsidy instruments, before using the general framework of “System Engineering” to base a precise recommendation for Swiss hydropower. The recommended mixture of investment contribution with discount reclamation appears the most appropriate instrument. Also, the short time horizon means that the subsidization can be quickly terminated if necessary. In parallel, it is a mature instrument since it is already used for other new renewable energies. The discount model allows reclaiming subsidies in case of an excess profitability. The strength of this study is its robust, comprehensive and all-encompassing methodology which can be replicated to other cases (for instance, other technologies or energy sources) and other countries.

Introduction

Worldwide, electricity production from hydro power could double by 2050 to reach 7000 TWh, and the main part of this growth will be coming from large hydropower plants (HPP) in emerging economies and developing countries [1,2]. In Switzerland, hydro power contributes to 60% of the total power generation [3], with an average of 36 TWh of produced electricity per year [4]. In the context of the new “Energy Strategy 2050” targets (thereafter called Swiss energy policy) and the intended nuclear power phase-out, around 40% of the electricity supply will have to be compensated by other energy means. Along with other renewable energies, hydropower represents a crucial pillar of both the current and future Swiss energy mix [5,37]. The actual sluggish electricity market makes it however questionable whether hydropower will be able to fulfill this role, since both an increase in capacity and a lot of investments in existing assets (for retrofitting and refurbishment) are necessary [6].

The envisioned extended role of renewables in electricity generation has been promoted through various government subsidies since 2008, notably with the introduction of feed-in remuneration at cost encouraging investments in renewables, including photovoltaic solar energy, hydraulic energy and small hydro, biomass energy or geothermal energy [7]. Despite this first step, the growing distortions in the market and the declining value of renewables on electricity trading markets have sparkled many debates around the subsidization of hydropower [8].

The paper is organized along three axes. It first explores and compare the existing subsidy instruments, and how they apply to hydropower in Switzerland. On this basis, this article then explains how the general methodology “Systems Engineering” can be used to assess the performance of those instruments, and how this methodology could be replicated either to other countries or to other technologies. Finally, through this detailed process, validated guidelines and recommendations are provided for a subsidy instrument to support the envisioned expansion of new hydro power capacities in Switzerland, along with other renewable energies, considered as pillars of the future Swiss

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Table 1
Overview of subsidy instruments.

Focus on	Subsidy instruments		
	Direct		Indirect
	Price-driven	Quantity-driven	
Investment [currency]	- Investment contribution - Credit discount	- Investment based tender process	- Eco-taxes - Green certificates
Production [currency/ MWh]	- Feed-in tariff/ premium payment - Bonus model	- Production based tender process - Quota regulation (with certificate market)	

energy transition. It is important to highlight that the methodology developed can be replicated to other countries, Switzerland's situation being used as a study case, thus underpinning the significance of this paper.

Comparison between existing subsidy instruments

Existing subsidy instruments

Existing subsidy instruments and support schemes are listed in Table 1 and discussed in the following paragraphs [7,9–13]. Their specific relevant to the hydropower situation in Switzerland is highlighted in each case.

Indirect subsidy instruments (eco-taxes, green certificates)

Indirect instruments such as certificate systems and incentive taxes charge caused external costs such as the costs of environmental pollution, by setting a price on the polluting activity. Thus, all (ecological) costs of the energy source are included within the electricity price ("polluter pays principle") [14]. Assuming that electricity from renewable energies is associated with low external costs, indirect instruments promote the development of renewable energies by indirectly changing the relative electricity prices.

Eco-taxes are a fiscal policy which tax environmentally-impactful energy sources [12]. While this measure has been established in Switzerland for heavy vehicles, it is not yet implemented for energy production [15]. **Green certificates** are an advanced version of tradable quotas [14,16], and they have recently gained a huge momentum in many European countries. It obliges producers, consumers or distributors to have a certain share of their electricity consumption or production that is deemed "green" (i.e. coming from a renewable energy source), through a state-controlled certification mechanism. This also allows a separation between the "physical" market where the electricity is sold at standard market prices (and competing with cheaper energy sources), and the certificate market (or eco-services market) which allows the producer to make up for this loss by selling the green certificates [17].

Difficulties in implementing this type of measures lie in the effective definition of the internalization charges as well as in the determination of potential quotas for the production of various energy sources. Additionally, these indirect promoting instruments need an appropriate legal basis. In Switzerland, this basis has not yet been fixed.

Investment contribution

Investment contributions are a one-time direct payment granted either in the form of a percentage of the total costs of the investment, or in the form of a predefined amount per installed MW [7,9,18]. The level of the investment is normally defined on a technology-specific basis; for hydropower, it is between 40% and 60%. The investments are paid to all providers of renewable energy that meet some predefined factual conditions.

This instrument suffers from two main drawbacks: first, the total spent cannot be determined beforehand, and second, the amount of electricity supplied by the plants supported through this mechanism cannot be foreseen. A subsidy price variable over time may compensate these weaknesses.

The Swiss Federal Office of Energy will apply this incentive scheme to support small hydropower (< 10 MW) rehabilitation and extension [19]. The new Energy Act, which has been accepted by popular vote in May 2017 and is also referred to as "Energy Strategy 2050", expresses that in the case a future excessive profitability of new large hydro plants, paid subsidies may be reclaimed [19]. The **contract reclamation** is an inverted version of the investment contribution. As soon as contractually agreed criteria are met, the repayment of the predefined amount is due.

Credit discount

Credit discount is a way of financing provided in return for a debt or repayment obligation, usually with advantages such as lower interest rates or with lower security requirements [20]. Credit discounts have a similar effect to that of investment contributions. This instrument is independent with respect to the funding level.

A disadvantage of this discount is that it is based on the size of the loan and not on the capacity installed. Given the same plant capacity, expensive investments get higher promotions compared to cheaper projects. In contrast to investment contribution, credit subsidies promote more expensive (and possibly less efficient) investments. Nevertheless, this type of subsidy is often used as a complementary tool.

Feed-in tariff

The feed-in tariff (FIT) guarantees a fixed compensation rate per unit of electricity produced from renewable energies, for a defined time period, and covers the difference between the production cost and the market price [21]. Producers have the guarantee that at least their production costs are covered and that they are not exposed to fluctuations of the electricity price, thus increasing the security of new projects. This rate is above the market price of electricity, otherwise the promotion would not be efficient [22]. This rate may also be corrected over time (through a process called dynamic adjustment), thus the quantity produced can be easily influenced (see Fig. 1). Additionally, it guarantees supplies with priority access and dispatch [23].

Since power supply companies are obliged to first buy the electricity produced from renewable energies (priority dispatch), the producers neither bear the costs for the marketing of their electricity nor the associated financial risks. Since the remuneration is higher than the market price and the power purchase is guaranteed regardless of the market demand, this instrument is not very close to the market [14,21,24]. The bearer of the costs is either the tax payer or the electricity consumer through a supplement on the electricity price.

Since 2008, the expansion of renewable energies has been promoted

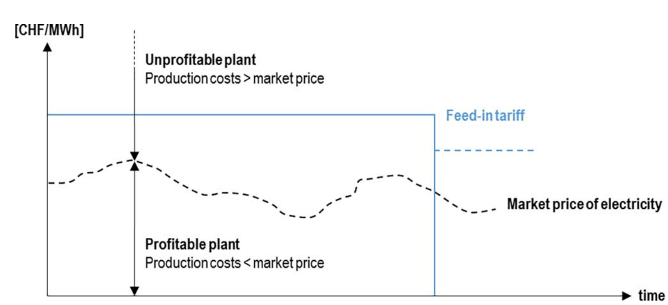

Fig. 1. Feed-in tariff, above the market price of electricity for a limited amount of time (blue line). Its value can be adapted (dashed blue line) to better influence the quantity produced. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in Switzerland, especially through its most important instrument: the KEV (*Kostendeckende Einspeisevergütung*). The compensation rate is defined annually by the Federal Council [25], and varies for various technologies. FIT is only used for small hydropower < 10 MW in Switzerland, for a duration of 20 years and for new facilities only. The old Energy Act defines a maximum of 1.5 cts/kWh [26], while the new legal framework sets the cap at 2.3 cts/kWh [27], see Table 2. The available budget remaining is rather limited compared to market demand, and a long waiting list is currently ongoing [28].

The KEV is mainly financed by a supplement on the electricity transmission costs on the high voltage power grid. The new Swiss Energy Act includes a change of the existing KEV system, where the current fixed feed-in tariff is in fact replaced by a variable bonus, which complements the sales revenue from the direct marketing of the electricity.

Bonus model

The producers of renewable energy receive a fixed bonus added to the current electricity price (Fig. 2). In contrast to the feed-in tariff system, all producers are thus exposed to market price fluctuations, independently of their subsidization or not [29]. This model is also sometimes called "*feed-in premium*" [15]. To optimize their profits, subsidized operators benefit from adjusting their production to the demand of the market, thus making a great contribution to power grid stability while securing their own investment costs. With regard to a further expansion of renewable energy, this is an important development.

Comparably to the feed-in tariff, electricity will only be produced if the production costs are equal or less than the sum of the market price of electricity price plus bonus, as shown on Fig. 2. The **discount model** is an inverted version of the bonus model. In the case that the electricity price is higher than a defined price level, a part of the surplus will be reclaimed in the form of a discount per MWh (see Fig. 3.

Power supply companies are normally not obliged to purchase the electricity produced from renewable energies. Power producers make their own marketing of their green electricity but also bear the associated risks. In this model, the amount of bonus as well as the costs bearer are determined by law. Like in the feed-in tariff system, the cost bearer may be the electricity consumer or the tax payer. Since there is no purchase obligation of electricity, producers have to align their production to the market needs, and this model is closer to market than feed-in tariff.

In Spring 2017, both the Swiss parliament, as well as the population by way of a referendum on the new Energy Act, have opted a temporary support to large hydropower (> 10 MW) [30]. The companies concerned by this measure are allowed a maximum market premium of 1.0 ct./kWh excluding VAT for electricity sold below market costs. The aid is financed by a maximum of 0.2 ct./kWh from the fund sustained by the supplement on the network. This support is limited to 6 years. Although the Swiss Federal Government has expressed the willingness to move out of a subsidy-based support policy for renewable energies towards a so-called ecological taxation framework, it is presently absolutely not clear if the Parliament and the Swiss population will move forward with this intention. Hence, at the end of the 6-year bridging period, a new subsidy scheme might be in discussion and the analysis presented in this paper thus entirely keeps its validity in possibly still difficult low-retail prices electricity market.

Tender processes

In a tender process, different tender modalities, bidding procedures and financing options are available [7].

In an **investment-based tender process**, the policy determines how much *capacity* should be installed for a specific amount of electricity needed to be produced. In an officially organized tender procedure, producers of renewable energy can apply for subsidies: this creates a market in which electricity producers compete for these incentives. In a functioning competition, all providers quote an electricity price equal to their average costs (cost per installed MW, incl. risk premium) and calculate the production at which these costs are minimized. Starting from the lowest tender, the subsidies are assigned in ascending order until the predetermined capacity is reached: the funded producers must provide the specified capacity and thereby receive a long-term support contract. The investment contribution seen previously represents an uncapped version of an investment-based tender process.

In a **production-based tender process**, the policy determines how much *electricity* should be produced and pays a fixed compensation per MWh for a guaranteed time. This compensation is higher than the market price. The awarding process is the same as previously: the subsidies are assigned until the predefined electricity amount is reached. Both those tender processes can be technology specific.

The marginal costs of the entire electricity production are equal to the marginal costs of the last selected project[1], which is used to cover the predetermined amount. All other subsidized plants produce at less or equal the marginal costs of this last project.

Quota regulation with certificate market

The policy sets a target amount of electricity to be produced from

Table 2
Supplement in Switzerland [cts/kWh] and legal cap.

	2014	2015	Legal cap	
			Present Energy Act	New Energy Act
Supplement [cts/kWh] including:	0.6	1.1	1.5	2.3
Water protection[1] [cts/kWh]	0.1	0.1	0.1	0.1
KEV [cts/kWh]	0.5	1.0	1.4	2.2

[1] The water protection includes measures to reduce the harmful effects of hydro peaking of hydro power plants and the restoration of the passages of waters for fishes in the area of hydro power plants.

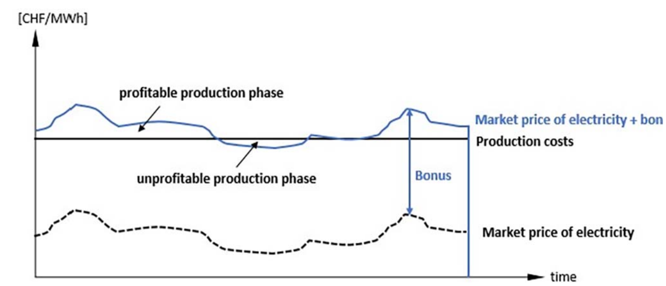

Fig. 2. Bonus model.

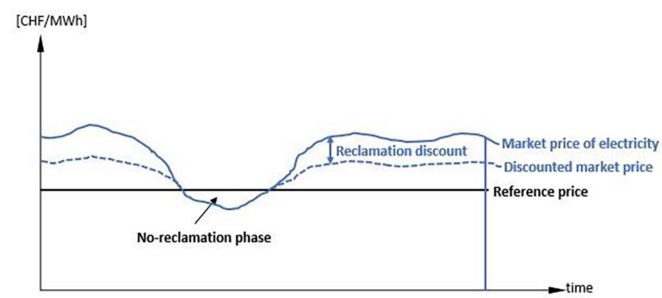

Fig. 3. Discount model.

[1] For the last project, the marginal costs are equal to the average costs.

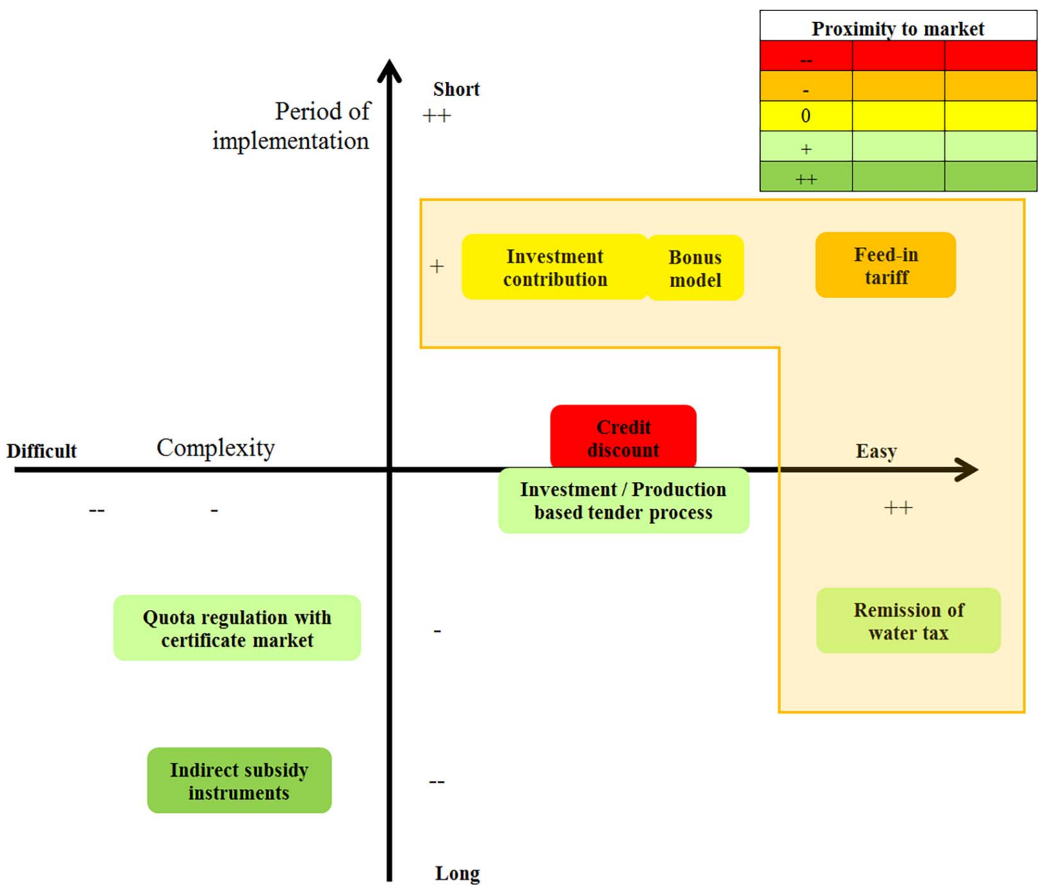

Fig. 4. Strengths (+/++) and weaknesses (−/−−) analysis of subsidy instruments. In yellow, subsidies that will be investigated further. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

renewable energy sources, and derives a quota for each power supply company to supply [7,16,31]. The producers have to organize the electricity sales and bear the corresponding risks. Alternatively, this quota can also be imposed on the electricity traders or the consumers of electricity. In this case, the purchase of the electricity from renewable energies is not guaranteed but settled by the market at market price.

The power supply companies can either generate the required amount of electricity themselves, purchase it from specialized producers or from a certificate market. The guaranteed price represents a premium for the production of electricity from renewable energies. By exceeding the quota, power supply companies can sell guarantees on the certificate market or transfer them to a subsequent period. In a market equilibrium, the guaranteed price corresponds to the difference between the marginal costs of the electricity and the present electricity price. If the power suppliers do not meet the quota, they can be liberated from the quota obligation by paying a penalty, which level defines the upper theoretical limit of the guaranteed price. To avoid this, the penalty can be defined as a percentage of the valid guarantee of origin price (e.g. 120%). The legislature determines how the income of this penalty system is used.

The additional costs of the electricity production or the purchase of guarantees are borne by the power suppliers, thus, they will try to pass all these costs to the customers by increasing electricity prices. As a result, the customers should subsequently try to reduce their electricity consumption. A functioning certificate market needs a certain trading volume, hardly reached by Switzerland's market size. Additionally, while a technology-specific separation would be possible, it does not make sense also in terms of market size.

Remission of water fee

According to the Swiss Constitution, Cantons have the right of water on their territory. The cantonal legislations allow the transfer of this right to communities or other entities like corporations. In general, this right is conferred to companies under private law. Hydropower in Switzerland is therefore mainly used based on concessions or grants. Comparably to the cantonal water sovereignty, the legal regulation of hydropower usage follows a federal model. However, the federal government has reserved the right for principle legislation as the competency to enact provisions on the water tax. This includes the specification of a calculation method and a cap rate to set the maximum water fee. Currently, this cap rate is 100 CHF/MW [32]. The maximum water tax is based on this rate and the average annual gross capacity of the power plant. Within the scope of this maximum, the cantons are free to define the water tax according to their own principles.

The franchisees have to pay this water fee annually which amount to ~400 Mio CHF of water taxes. This corresponds to about 1.2 cts/kWh. This is more than half of the total charge of hydro power through the official community [32].

A temporary reduction or even remission of the water tax would therefore relieve the power plant operators. Because of the federal organization of the energy policy, the use of this subsidy measure is presently leading to a lengthy and complicated debate. In addition, this discussion also includes the issues of the mountain cantons and the inter-cantonal budget; indeed, the water fee income is an important component of the public budgets in certain areas of Switzerland.

Strength-weakness analysis of subsidy instruments

There are several criteria to evaluate subsidy instruments [9], and this study highlights the following main criteria:

- **Proximity to market:** The subsidization should not eliminate the price signals resulting from the market dynamics. A high electricity demand – respectively a low electricity supply – creates a higher

market price. Thus, the financial incentives should promote an adaptation of the production to demand, to both optimize available funds and help stabilize the power grid.
- **Complexity:** The subsidy system should be as simple as possible to reduce administrative efforts and increase confidence of the producers.
- **Period of implementation:** The subsidy measures should be quickly operational. With regard to the conversion of the support program for renewable energy planned in the medium-term phase of the new Swiss energy policy, a quick termination of the instrument is advantageous.

In the following Fig. 4, the known subsidy instruments are rated according to these criteria, showing a snapshot of the current situation in Switzerland. It is stressed again that the aim of the present study is not to compare subsidy-based frameworks to alternative policies such as tax-credit designed to support the penetration of renewable energies; for such a study, one can refer to [38].

New large hydropower plants, along with substantial refurbishment and repowering of existing hydropower schemes are needed to achieve the electricity production targets defined by the new Swiss energy policy [4,19]. However, in the current market environment, such projects cannot be built and operated cost-effectively and electricity prices are expected to remain low in the short and medium-term. Different instruments are used to support the development of renewable energy, including hydropower. The current systems are continuously optimized, extended and adapted. “Proximity to market”, “complexity” and “period of implementation” were evaluated as important criteria for subsidy instruments. The strength-weakness analysis, which was performed on the basis of these criteria showed that none of the known instruments stands out clearly as the obvious best subsidy solution. Different subsidization approaches are currently being discussed in politics and in the economy, as well as possible reclamation of paid subsidies.

Methodology and objectives

Methodology of Systems Engineering

One definition of Systems Engineering is “a robust approach to the design, creation, and operation of systems. It consists of identification and quantification of system goals, creation of alternative system design concepts, […] selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets the goals” [33].

The methodological approach of this study is thus based on those principles of Systems Engineering, and aims at achieving a transparent definition and justification of a possible subsidy instrument for new large hydro power [3] (Fig. 5). From a current overview of existing

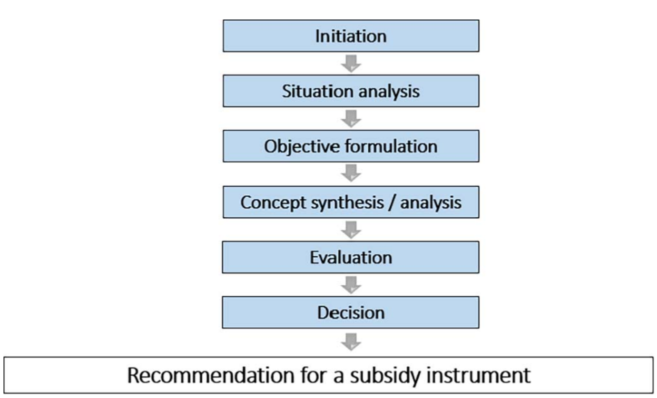

Fig. 5. Steps of the Systems Engineering approach.

subsidy instruments and policies in Switzerland, a strength-weakness analysis of those instruments is performed. This formed the basis upon which objectives could be derived, to implement a first concept analysis. As a result, a recommendation for a subsidy instrument for new large hydro power is proposed.

According to the Systems Engineering approach described above, the situation analysis will be described in the following paragraph, and is also established on the previous chapter regarding the existing subsidy instruments. The objectives are formulated next, thanks to a precise list of criteria and their relative priorities (defined as rather mandatory or nice-to-have).

Assessment of the Swiss situation

Currently in Europe and especially in Switzerland, hydropower is facing a wide array of challenges, ranging from extremely low electricity prices and partially liberalized market, leading to an unfavorable market situation. It is concomitantly viewed as a central piece of the new Swiss Energy Policy, which sparkled many debates regarding its future and its role within the envisioned energy transition in Switzerland.

The new Swiss Energy Act defines as production target for 2035 at least 37,400 GWh per year from hydro power [5,37], of which 2400 GWh are currently missing [6]. A subsidy instrument for small hydro (up to 10 MW) has been already introduced in 2008 to help support the achievement of these targets [7]. However, despite projects for small hydro power plants with a yearly production of approximately 900 GWh [8], only 35% may be eventually implemented [9].

The missing 2100 GWh per year would need to be covered by new hydro power plants, either through refurbishment, retrofitting or new projects. The average production cost of such projects has been estimated at 141 CHF/MWh [10] (~130 €/MWh in 2016), including operation and maintenance costs, water and other taxes, debt and equity capital costs, depreciation and other costs. This is more than three times more expensive than the current electricity market price (< 50 CHF/MWh, i.e. 45 €/MWh in 2016). This difference can be explained by multiple factors. First, a steady decline in electricity prices combined with a reduction in the peak/off peak prices has wrecked a lucrative business model for Swiss hydropower, thus sparking national political debate around the possible subsidization of large hydropower plants.

Objectives

The main objective of this study is a tailored recommendation for a subsidy instrument supporting new large hydropower plants in order to achieve the production targets defined by the new Swiss energy policy. The decision whether to support or not is not part of this study. It is stressed again that, although the new Energy Act has set a temporary six-year provision for large hydropower plants, the presented analysis keeps its full meaning since nothing has been politically and policy-wise fixed for the end of this bridging period.

A distinction is made between the following types of objectives [34,35]:

- *Mandatory targets* are essential system requirements which must be fully determined in the objectives formulation and which have the maximum priority in the implementation (‘must’ objectives). They are linked to *restrictions* which set limits for specific properties.
- *Non-mandatory targets* are system requirements which could be described as nice-to-have (noted ‘W’). These requirements are desirable and add value to a solution. *Optimizations* can, but need not be implemented.

This catalogue of objectives in the table below is used to evaluate the solution elaborated in the following chapter.

The next step of concept synthesis and analysis is used to generate

Table 3
Catalogue of objectives for the subsidy instrument Mandatory targets are noted 'M', Non-mandatory 'W', Opportunities 'O', and Restrictions 'R'.

Objective:
Focused recommendation of a subsidy instrument, with which new large hydro power plants (> 10 MW) can be supported in the future.

Objective class		Objective formulation	Quantification	Type
Systemic objectives				
Structural objectives	1	Simple and fast implementation of subsidy instrument	Subsidy instrument: Consideration of existing instruments and processes	M
	2		Subsidy instrument: Compatibility with existing system for fast implementation	M
	3		Subsidy instrument: Low complexity for simple and obvious handling for the authorities	M
	4		Subsidy instrument: Broad political and economic acceptance	W
	5	Implementation of reclamation instrument to prevent over-subsidization	Reclamation instrument: Independence from choice of subsidy instrument	W
	6		Reclamation instrument: Consideration of existing processes	M
	7		Reclamation instrument: Compatibility with existing system for fast implementation	M
	8		Reclamation instrument: Low complexity for simple and obvious handling for the authorities	M
	9		Reclamation instrument: Broad political and economic acceptance	W
	10	Support of subsidy instrument with supplementary mechanism	Usage as additional support for the main subsidy instrument	O
Financial objectives	11	Consideration of expansion targets	Simple preliminary determination of the total subsidy requirements	W
	12		Efficient use of available subsidization funds	W
	13		Inducement to start construction projects to reach expansion targets	W
	14	Simple adjustment of subsidization	Insensitivity of the instrument to changes and extensions	W
	15		Fast termination of subsidization (regarding next phases of Energy Strategy 2050)	M
	16	Consideration of market demand	Retention of market signals as incentives to produce electricity according to the market demand	M
	17		Low distortion of the electricity market price by the subsidization (Merit-Order)	W
Restrictions				
	18	Compliance with legal basis	Consideration of laws (e.g. Energy Act) in the choice of subsidy instrument	R[3]

[3] The legal compliance is mandatory for a future subsidy instrument. It is assumed that the basic features of the current draft of the new Energy Act will not change significantly.

and evaluate solution ideas for subsidy instruments for large hydro power. First, in a rough synthesis, ideas are developed without limitation (brainstorm). Next, a rough analysis intuitively checks the suitability of the proposals. The remaining ideas are then worked out and characteristics are shown in a detailed synthesis. Finally, the detailed analysis of the solution is done explicitly regarding completeness and feasibility. These four steps should be done iteratively several times until the solutions proposed are sufficiently recognized and described [34].

Rough synthesis and analysis

Many subsidy instruments possible are described in the synthesis phase, and are possible solutions to the problem. The criteria against which the solutions are compared are described in detail in the catalogue of objectives (see Table 3). This already eliminated some of the ideas. Notably, the following instruments are considered unsuitable:

- **Indirect subsidy instruments (taxes)**: These tools would require a fundamental change in the legal basis within the next few years.
- **Credit discount:** This instrument supports costly projects more than lower priced ones. It is generally regarded as being inefficient.
- **Quota regulation with certificate market:** To get a large and competitive market for renewable energies it is useful to involve all energy producers, including new large hydro power. This does especially apply for a small market such as Switzerland [36]. Therefore, the current feed-in tariff subsidization system would have to be terminated. As in the second phase of the new Swiss energy policy a total change of the subsidy system to an incentive tax system is planned, such an intermediate system change would additionally increase the administrative efforts. This instrument might have been useful had it been chosen for the subsidization of all renewable energies right from the beginning of the support era.
- **Tender processes:** To achieve the defined expansion targets, the whole expansion potential of large hydro power has to be more or less realized. This potential seems to be too small for a meaningful tender process.

Detailed synthesis – development of comprehensive solutions

The next step is the detailed synthesis based on the remaining subsidy idea. A morphological box is used for this purpose. In this method the specifying properties are determined and listed in the column on the left side of the box (1–5). The properties must be independent from each other and suitable. Next, possible options of each property are set in the columns (A – C) of the box. The result is a matrix in which each combination of options of all properties is theoretically a possible solution (see Table 4).

The combination of one option (A- > C) for each step (1- > 5) leads to various solutions (tree of possibilities with theoretically 3^5 leaves). However, it is important that the chosen options are compatible and no contradictions arise within them, therefore, leaves containing contradictions are discarded.

Two main categories of inconsistent options can be derived. First, many solutions are time-inconsistent, meaning the logical process of the five steps is not logical from a time point of view. For instance, it is incoherent to pay a production-based fee to power plants which are not yet built to pre-finance to construction: this removes all leaves containing the combination (1A, 3B), or (1A, 5A). The second category regards administrative and responsibility challenges. Administrative efforts should not be increased.

Few possibilities have been found as non-contradictory. Among the non-contradictory ones, the following possibilities are found as the most meaningful combinations. It is useful to highlight that they bear a

Table 4
Morphological box.

Property		Options		
#		A	B	C
1	Subsidization	Fee based on production	Fixed fee	Exemption from some taxes or surcharges
2	Scope	Total coverage of costs	Partial coverage of costs	Partial and adjustable coverage of costs
3	Timing	During the construction	Before the construction	After the construction
4	Control mechanism	Check of the production	Check of the work achieved	Trust / Absence of control
5	Reclamation (Reversal of subsidization)	CHF/MWh – An amount is invoiced for every MWh produced (Discount)	CHF – A predefined amount is reclaimed as soon as stipulated criteria are met	Increase existing taxes or surcharges

strong resemblance to already known subsidy instruments (more detail is available in Appendix):

- Feed-in tariff (1A, 2A, 3C, 4A, 5A)
- Bonus system (1A, 2C, 3C, 4A, 5A)
- Investment contribution (1B, 2B, 3A/B, 4B, 5B)
- Remission of water tax (1C, 2B, 3C, 4A, 5C)

While other combinations are also possible, they are mostly theoretical and do not make a lot of sense from a practical point of view.

Detailed analysis – evaluation of solutions

The final step is the **detailed analysis**, to choose the most appropriate solution among the four remaining approaches (feed-in tariff, bonus system, investment contribution or remission of water tax).

The following procedure was chosen for the evaluation: all possible solutions were graded against the catalogue of objectives (see Table 3), and scored to reflect the fulfilment of these objectives on a scale of −10 to +10. The current state is valued as 0; negative values indicate noncompliance, while positive values mirror the degree of fulfilment (improvement).

However, a critical improvement valued with a +10 does not mean that an absolute optimum has already been reached. The following Kano weighting is performed:

- **Fulfilment of 'must' objectives** (M: ˆ1): Positive evaluation values for 'must' objectives are weighted linearly. This corresponds to the increase of the customer satisfaction for basic factors on the positive side of the Kano model.
- **Non-fulfilment of 'must' objectives** (M: ˆ2): Negative evaluation values for 'must' objectives are squared (the negative sign is retained). This corresponds to the decrease of the customer satisfaction for basic factors on the negative side of the Kano model.
- **Fulfilment of 'wish' objectives** (W: x2): Positive evaluation values for 'wish' objectives are weighted twice. This corresponds to the increase of the customer satisfaction for excitement factors on the positive side of the Kano model.
- **Non-fulfilment of 'wish' objectives** (W: x1): Negative evaluation values for 'wish' objectives are weighted linearly. This corresponds to the decrease of the customer satisfaction for excitement factors on the negative side of the Kano model.

All individual scores are then additionally weighted to obtain a total score reflecting that 'must' objectives weigh more than 'wish' objectives. The sum of all weighted values gives the relative achievement of objectives, noted AO-value.

Compliance with restrictions is very important and usually a solution which do not fulfil one should be discarded. However, promising solutions should not be discarded too early, especially if it has high scores everywhere else. In this evaluation, restrictions are therefore accounted as factors to the AO-value. Each fulfilled restriction is included in the evaluation with the multiplier 1, each unfulfilled restriction with the multiplier 0.5. In the case of a negative AO-value, the multiplier is 2 for unfulfilled restrictions. Thereby the final score value (FS-value) for each solution is calculated. This ensures that the restrictions are considered separately and that the evaluation deteriorates noticeably for a non-fulfilment.

Evaluation of solutions 1 to 4 and their relative achievement are detailed in Table 11; a summary is described in Table 5 below.

The comparison of the AO-values shows that solution 1, similar to the current feed-in tariff instrument, is far behind and therefore not useful for the support of large hydropower, with a lead for solution 3. By adding restrictions (FS-value), solutions 1 and 4 are further shrunken. In the case of solution 1, the devaluation concords with the expected content of the new Swiss Energy Act, which assumes that in the future the feed-in tariff instrument will no longer be valid for the construction of new plants and expansion projects. Solution 4 is devalued because an increase of the water tax for a possible reclamation is not covered by law. If a political agreement is ever achieved, this approach could be a useful support for the main subsidy instrument. For all these reasons, approaches 1 and 4 are abandoned.

Solution 3 (investment contribution) and solution 2 (bonus model) are good candidates since the incentives for an electricity production depend on the market demand. In the case of investment contribution, the efficient use of subsidies id a known weak point but by using a reclamation instrument, this point can nevertheless be partially defused. For solution 2, deductions are made for the complex procedure to define the bonus amount and the speed of the subsidization termination. Bonus payments are normally granted for several years. With regard to the planned changes of the support system in the context of the new Swiss energy policy, quickly terminable projects make sense.

Since the solutions 2 and 3 are quite close together (see Table 6), yet no definite best solution can be determined on the basis of this evaluation and both will be further evaluated in the next paragraph.

Recommendation of a subsidy instrument

Since the previous evaluation revealed no clear favorite, the required processes and their parameters as well as their advantages and disadvantages are explicitly listed again for the remaining solution 2 and 3.

Based on the evaluation and the pros and cons analysis done in this

Table 5
Ranking of solution approaches 1–4.

Ranking	Solution number	AO-value	FS-value
I	3 – Investment contribution	134	134
II	2 – Bonus model	84	84
III	4 – Remission of water tax	50	25
IV	1 – Feed-in tariff	−24	−48

Table 6
Advantages and disadvantages of both solutions.

		Advantages	Drawbacks
Solution 2	**Subsidization** "BONUS MODEL" In addition to the electricity sales revenue, the plant operators receive a bonus per MWh fed-in. The duration is defined in advance.	+ Processing and monitoring of production well established (KEV system).	- Long-term subsidization instrument. The planned switch from a support system to an incentive taxes system could cause conflicts due to the overlap of two systems. - Need for an ongoing servicing of this reclamation instrument. To calculate the amount of the discount, the present electricity price must be taken into account. Electricity price plus bonus should be set in advance. - Increased administrative efforts (each project must be rated)
	Reclamation "DISCOUNT MODEL" In case of an excessive profitability of the power plant, subsidies are reclaimed with a discount per MWh fed-in.	+ Monitoring of production well established. + High clarity of the system: only one criterion (electricity price > reference price) must be met for a reclamation.	- Need for an ongoing servicing of this reclamation instrument. To calculate the amount of the discount, the present electricity price must be taken into account. - Increased administrative efforts (each project must be rated)
Solution 3	**Subsidization** "INVESTMENT CONTRIBUTION" Part of the total investment costs are covered with a financial contribution.	+ Manageable time horizon + VAccounting processes already established.	- Compliance with intermediate targets difficult. - Increased administrative efforts (each project must be rated)
	Reclamation "CONTRACT RECLAMATION" In case of an excessive profitability of the power plant, subsidies are reclaimed, based on a contractually agreed criteria.	+ Low monitoring required (since reclamation does not directly depend on electricity production).	- Compliance issues with contractual reclamation terms - Increased administrative efforts (each project must be rated)

study, a mixture of the investment contribution (from solution 3) with a discount reclamation model (from solution 2) is recommended as the most appropriate subsidy instrument for new large hydro power.

Accounting processes which can be used for investment contribution are well known from large general construction projects. By an appropriate selection of significant project milestones (such as start of the construction phase, the commissioning of the plant or the achievement of the MWh production targets for a given period of operation), any controversial subjects in the accounting can be eliminated. Another advantage of this instrument is the short time horizon and thus the fast termination. This would prevent in advance system interface problems, which could arise from the transition from the subsidy system to the planned incentive tax system (phase 2 in the new Swiss energy policy).

Additionally, a clear initiation of the reclamation would be a decisive advantage of the discount model. It only hinges on the condition that the current electricity price must be higher than the reference price.

Conclusion and policy implications

In Switzerland, electric utilities are presently facing a difficult situation with respect to the economic viability of their respective large hydropower assets. In this respect, the Swiss Parliament and population have recently decided to adopt the bonus model to support the hydropower sector over a very limited period of time, namely 6 years. The in-depth analysis presented herewith allows considering a more long-term and sustainable subsidy framework for large hydropower that goes beyond provisional political measures. Indeed, to achieve the production target set by the new Swiss energy policy, the refurbishment of existing, as well as the development of – a probably limited but nevertheless non-negligible number of – new plants is necessary. Additionally, given the forecast five from now of electricity prices and the current extent of the subsidies, a possible prolongation of the support model or a new support scheme for large hydro power is still relevant. The choice and implementation of a long-term subsidy instrument for new large hydro power should be politically and economically discussed and this paper aims to provide quantitative insights.

By applying the principles of Systems Engineering, various solutions for a subsidy instrument are developed and compared. Since none of the analyzed instruments is optimum, a recommendation is made to adopt the investment contribution approach. In Switzerland, this would be the most meaningful subsidy instrument for new large hydro power and has in fact been considered very seriously in parliamentary deliberations. In the case of excess profits in the future, a reclamation mechanism could be added (discount model).

A great strength of this methodology is its replicability to other countries as well, and in other contexts.

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Appendices

Possible solutions

From the methodology of Systems Engineering, the detailed synthesis has led to the development of four solutions which all bear resemblance to existing instruments. More details are given in the paragraph below.

Solution 1 (similar to the feed-in tariff)

Solution 1 is similar to the feed-in tariff system. For each fed-in MWh the producers will receive a fixed cost covering tariff. In case of the large hydro power this tariff may be determined for each plant separately. The construction of the plant must be pre-financed by the owners. The payment is then done on the basis of the produced amount of electricity, which is monitored by a guarantee of origin system. The instrument is complemented with a reclamation mechanism. It is used to reclaim the subsidies, should the conditions of the electricity market permit an excessive profitability of

Table 7
Solution 1 (similar to the feed-in tariff).

#	Option	Description
1	A	CHF/MWh – A surcharge is paid for every MWh produced
2	A	The total costs are covered
3	C	After the construction
4	A	The subsidies are paid based on the production
5	A	CHF/MWh – An amount is invoiced for every MWh produced (Discount)

Table 8
Solution 2 (similar to the bonus system).

#	Option	Description
1	A	CHF/MWh – A surcharge is paid for every MWh produced
2	C	A part of the total costs is covered, which can change over time
3	C	After the construction
4	A	The subsidies are paid based on the production
5	A	CHF/MWh – An amount is invoiced for every MWh produced (Discount)

the plant. For this purpose, an inverse bonus system is planned. If the electricity price is higher than a defined level, a part of the surplus will be reclaimed in the form of a discount per MWh (see Table 7).

Solution 2 (similar to the bonus system)

Solution 2 bear resemblance to the bonus model. The only difference to approach 1 is the amount of the paid out charge. The sum of electricity price plus bonus should be approximately in the range of the production costs. Thereby the incentive to adjust the production to the marked demand remains for the producers. Again, each project can be considered individually. As a reclamation mechanism, the inverse bonus instrument as described in approach 1 is planned (see Table 8).

Solution 3 (similar to the investment contribution)

Solution 3 is similar to the investment contribution (see Section "*Strength-weakness analysis of subsidy instruments*"). A part of the allowable project costs is subsidized. The upper limit of the subsidization can be defined in different ways. For example, as a percentage of the total costs or as fixed contributions for essential components of the project. The payment is meaningfully done in tranches. By reaching defined intermediate projects targets, a predetermined amount of the subsidization is paid. As a reclamation mechanism, an inverse investment contribution can be used. As soon as contractually agreed criteria are met, the repayment of the predefined amount is due (see Table 9).

Solution 4 (similar to the remission of water tax)

Solution 4 corresponds to the remission of the water tax. The extent of the subsidization can be adjusted by the amount and duration of the remission. As in solution 1 and 2, the owner has to pre-finance the construction of the power plant. The criterion for the remission of the yearly payment of the water tax can be a defined electricity production volume. This can be exactly monitored with the data from a guarantee of origin system. For the reclamation of an over subsidized amount, a temporary increase of the existing tax can be used (Table 10).

Evaluation grid of solutions

Processes

Subsidization process of solution 2 (bonus model)

- Evaluation of the project (e.g. by the BFE, the Federal Office of Energy, as it already has worked out appropriate studies.
- Clarification of the availability of funds.

Table 9
Solution 3 (similar to the investment contribution).

#	Option	Description
1	B	CHF – A contribution is paid
2	B	A part of the total costs is covered
3	A/B	During/Before the construction
4	B	The subsidies paid on the basis of the achieved work progress (functional specification)
5	B	CHF – A predefined amount is reclaimed as soon as stipulated criteria are met

Table 10
Solution 4 (similar to the remission of water tax).

#	Option	Description
1	C	Waive existing taxes or surcharges
2	B	A part of the total costs is covered
3	C	After the construction
4	A	The subsidies are paid based on the production
5	C	Increase existing taxes or surcharges

- Notification of the subsidy decision (Planner can take legal action against the decision).
- Demand of the project progress documents (e.g. building permit).
- Demand of the commissioning protocol.
- Monitoring of the production via the HKN guarantee of origin system.
- Calculation of the bonus due.
- Decision to pay the subsidization amount.

Subsidization process of solution 3 (Investment contribution)

- Evaluation of the project.
- Clarification of the availability of funds.
- Notification of the subsidy decision (Planner can take legal action against the decision).
- Demand of the project progress documents (e.g. building permit).
- Demand of the commissioning protocol.
- Monitoring of the construction progress.
- Calculation of the investment contribution due.
- Decision to pay the trances on the fulfilment of the project intermediate targets.

Reclamation process of solution 2 (discount model)

- Evaluation of project.
- Notification of the reclamation decision (Planner can take legal action against the decision).
- Monitoring of the production via HKN guarantee of origin system.
- Calculation of discount due.
- Decision to account reclamation amount.

Table 11
Detailed evaluation grid of solutions 1 to 4.

Objectives (from Table 3)	Solutions							
	1		2		3		4	
	Kano	Value	Kano	Value	Kano	Value	Kano	Value
M 1	ˆ1	10	ˆ1	8	ˆ1	8	ˆ1	0
M 2	ˆ1	10	ˆ1	8	ˆ1	8	ˆ1	10
M 3	ˆ1	8	ˆ2	−16	ˆ1	6	ˆ1	0
W 4	x1	−4	x2	8	x2	12	x1	−6
W 5	x2	8	x2	8	x2	16	x2	0
M 6	ˆ1	8	ˆ1	8	ˆ1	4	ˆ1	0
M 7	ˆ1	8	ˆ1	8	ˆ1	8	ˆ1	10
M 8	ˆ1	6	ˆ1	6	ˆ2	−16	ˆ1	0
W 9	x2	12	x2	12	x2	8	x1	−8
AO-value rec		42		42		20		2
O 10	–	0	–	4	–	8	–	10
W 11	x2	12	x2	8	x2	16	x2	20
W 12	x1	−8	x2	8	x1	−4	x1	−4
W 13	x2	20	x2	12	x2	16	x2	4
W 14	x2	12	x2	8	x2	16	x2	4
M 15	ˆ2	−16	ˆ2	−16	ˆ1	8	ˆ2	−16
M 16	ˆ2	−100	ˆ1	6	ˆ1	8	ˆ1	10
W 17	x1	−10	x2	4	x2	12	x2	16
Subtotal M		−66		12		34		14
Subtotal W		42		68		92		26
Subtotal O		0		4		8		10
AO-value		−24		84		134		50
AO w/o rec		−66		42		114		48
R 18	2		1		1		0.5	
FS-value		−48		84		134		25

Reclamation process of solution 3 (Contract reclamation)

- Evaluation of the project.
- Notification of the reclamation decision (Planner can take legal action against the decision).
- Monitoring of the business progress.
- Calculation of reclamation amount due.
- Decision to account reclamation amount.

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