Promoting renewables cost-effectively:

Empirical analysis of photovoltaic power production in Switzerland

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Abbreviations

AC	Alternating current
CCS	Carbon capture and storage
CHF	Swiss Francs
CO_2-eq.	Carbon dioxide equivalents
DC	Direct current
EnG	Swiss Energy Act
EnV	Swiss Energy Ordinance
EPBT	Energy payback time
GDP	Gross domestic product
GHG	Greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KEV	Kostendeckende Einspeisevergütung
kWh	Kilowatt hours (quantity of produced energy)
kWp	Kilowatt peak (measure for installed capacity)
LCA	Life-cycle analysis
MWp	Megawatt peak (measure for installed capacity)
O&M	Operation and maintenance
PM10	Particulate matter <10µm
R&D	Research and development
RET	Renewable energy technologies
RES	Renewable energy sources
ROI	Return on investment
RR	Resource rents
SFOE	Swiss Federal Office of Energy
USD	US Dollars
WACC	Weighted average cost of capital

1 Abstract

Electricity generation based on photovoltaic (PV) technology has not yet reached market maturity demonstrated by current high production costs. In order to ensure an economic, environmentally-compatible and diversified electricity supply in the long term, the Swiss legislator adopted a cost-covering feed-in remuneration system for renewable energy sources in 2007. Such feed-in remuneration systems can easily suffer from cost-ineffectiveness[1] since substantial variances in specific output and costs appear among operators. The present study seeks to identify and quantify cost-ineffectiveness among roof-mounted photovoltaic power plants recorded in the Swiss promotion system ‘KEV’[2]. In the context of an empirical analysis, a sample of 65 plants was investigated with regard to actual investment costs. The present study provides empirical evidence for the existence of cost-ineffectiveness inherent in the Swiss supporting system KEV. This can be substantiated by a share of 60% of investors realizing a so-called ‘resource rent’ which is defined as an economic profit above the normal rate of return of 5% that is included in the feed-in remuneration.

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[1] Within the context of this study, the term ‘cost-effectiveness’ refers to the relation between the targets of a policy instrument and the costs that appear to reach the targets. A policy is declared to be cost-effective if it achieves its targets at least costs. Thus, cost-effectiveness is a measure for proximity of average costs per unit of target achievement to minimum costs needed to reach one unit of target. In the context of public promotion policies, the term ‘fund-ineffectiveness’ may equally be used since public funds are spent on promotion.

[2] Stands for ‘Kostendeckende Einspeisevergütung’.

2 Introduction

2.1 Initial position

The revised Swiss Energy Act (EnG) stipulates an extension of renewable electricity production to 5400GWh per year by 2030[3], which equals to around 10% of current Swiss electricity consumption. Thereby, hydro power (up to 10MWp), photovoltaic energy, wind power, geothermal power and biomass energy are considered as renewable electricity technologies. The extension aims for enhancing security of supply, contributing to the achievement of GHG emission reduction targets and promoting renewable energy technologies. The Swiss legislator adopted the cost-covering feed-in remuneration system KEV as major policy measure in order to reach the quantitative target. It allows any plant operator to feed-in the total amount of produced renewable electricity into the Swiss electricity grid at cost-covering tariffs. The difference between feed-in tariffs and the actual market value of electricity is covered by a fee of 0.9 cents per kWh surcharged on consumed electricity. Shortly after adoption, the promotion system for renewable energy sources (RES) exhibited obvious deficiencies. The feed-in remuneration triggered a boom in investments, notably in the field of photovoltaics, leading to a system blocking due to oversubscription. A large number of over 5000 recorded plants were put on a waiting list, whereby photovoltaic technology is worst affected. As a consequence, the promotion scheme doesn’t serve all its purposes for the moment.

2.2 Purpose of the study and research question

The oversubscription of the Swiss promotion system raises the question of the appropriateness of incentives offered by the system. It seems intuitively natural that incentives for investors are too strong with regard to the target of the policy measure. On the one hand, the possibility of generating economic profits supplementary to the normal rate of return[4] due to favorable site-characteristics is inherent in the system providing additional financial incentives. On the other hand, the potential of investors placing their funds from conviction of necessity may have been neglected. Anyhow, namely overestimated total costs, underestimated specific output rates or system design deficiencies are possible causes for wrong incentives to investors. The present study aims to empirically evaluate actual total investment costs of PV plants recorded in the remunera-

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[3] An additional production of 5400GWh with respect to the 2005 output level is required.
[4] Feed-in tariffs provided by the Swiss supporting system KEV include a normal rate of return of 5% on equity and debt capital. As feed-in tariffs are fixed, investors with favorable site-characteristics can realize an economic profit beyond the normal rate of return of 5%.

tion system KEV. Based on actual production output of 2009 and investment cost data, actual production costs are calculated. By comparing actual production costs with remunerated feed-in tariffs, possible system ineffectiveness in terms of economic profits is determined. Consequently, the research question can be formulated as follows: May the existence of assumed promotion system ineffectiveness, measured in terms of economic profits, be demonstrated by investigating a sample of PV plants recorded in the KEV? In order to achieve the targets of this study, a cross-section analysis with a sample of 65 roof-mounted PV plants was designed. Data was mainly collected on site based on financial records of plant operators and with the consent and support of the Swiss Federal Office of Energy. Based on the empirically determined results, recommendations for promotion system adaptations will be formulated.

2.3 Limitations

The present study is faced with a range of framework conditions limiting the force of expression of the outcome. Firstly, the study has been realized in the context of a master thesis which implicates substantial restrictions regarding time exposure. Since data collection and validation absorbed a large share of time resources, the analysis of data could not be exhausted to its limits. Secondly, the number of observations is rather small and their distribution suboptimal with respect to geographical and environmental parameters. Thirdly, the heterogeneity among observations is moderate which implies strong constraints for empirical analyses. Heterogeneity could partly not be captured either due to the absence of empirical values (maintenance costs, grid amplification e.g.) or due to missing willingness of plant operators to declare (interest rates e.g.). Fourthly, the empirical analysis is mainly based on assumptions that are equal to the assumptions given in the context of the system KEV. Thereby, the outcome of the study is more convincing with regard to current feed-in system properties. In conclusion, the present study may be characterized as a pilot study in the field of evaluating the Swiss promotion system KEV. Repeating the study in a decade would probably provide more detailed information as the quantity of empirical values will considerably increase.

2.4 Structure of thesis

The present study is composed of a theoretical part (sections 3 and 4) and an empirical part (section 5 to 7). Section 3 provides theoretical evidence for the necessity of RES promotion and outlines the relevant framework of the Swiss promotion system KEV. In section 4, relevant output and cost factors as well as GHG balance of PV technology are discussed. Data collection and validation, data properties and methodological aspects are described in section 5. Section 6 and 7 show and discuss the results. Conclusive remarks are finally presented in section 8.

3 Promotion of renewable electricity production

3.1 Energy supply and climate

Today, there is a broad scientific consensus about the positive effect of greenhouse gas (GHG) emissions on global mean temperature. Currently, global annual emissions of around 28Gt of CO_2-equivalents enforce the greenhouse effect in the atmosphere and accelerate global warming (IEA 2010). Energy-related GHG emissions[5], mainly from fossil fuel combustion for electricity production[6], transport and heat supply, account for around 70% of world's total emissions (IPCC 2007). Thus, the theoretical GHG emission reduction potential related to transport, transformation and end use of fossil energy sources is enormous.

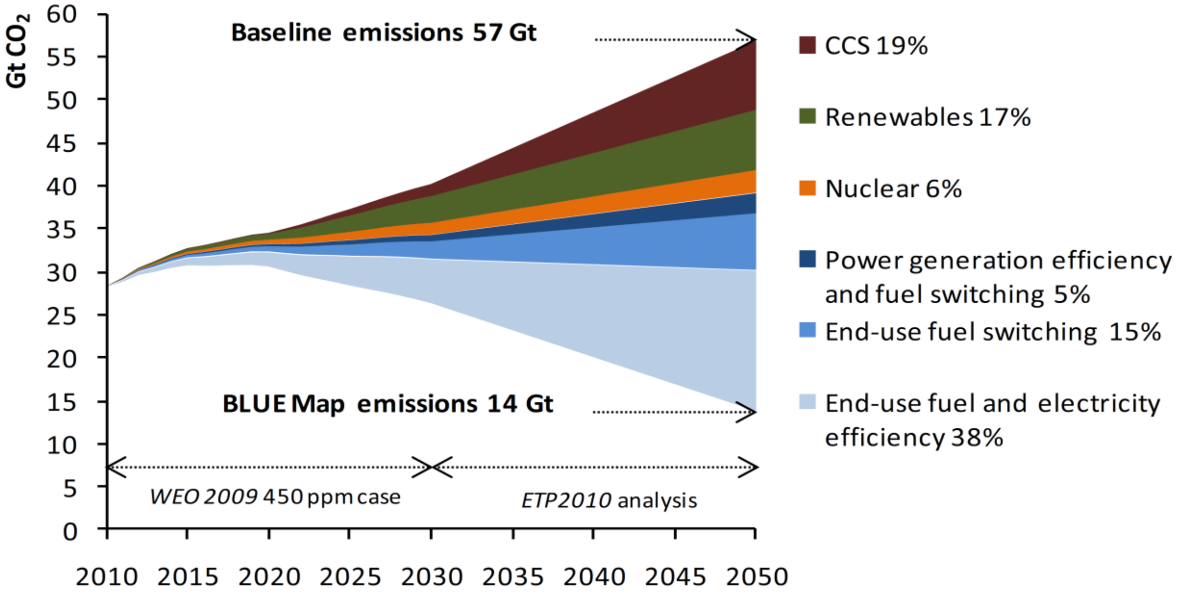

Fig. 1: Key technologies for reducing global CO_2-emissions under the BLUE Map Scenario (IEA 2010).

When facing the challenges of substantial GHG emission reductions, a global and integrated response is required. With respect to the high share of energy related emissions, the energy sector has to play a central role in this response (IEA 2010). According to scenario calculations[7] presented by the International Energy Agency (IEA), a bundle of energy related technologies covers

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[5] Including the GHGs carbon dioxide, methane and nitrous oxide.

[6] This is currently not true for the case of Switzerland where electricity production is almost free of GHG emissions. It may change in the foreseeable future as a high share of installed nuclear capacity in Switzerland has to be replaced, whereby natural gas technology *inter alia* is in discussion.

[7] IEA scenario analysis deals solely with energy related CO_2-emissions.

the potential to reduce global energy related emissions by 50 to 85% by 2050 (BLUE Map scenario[8]) relative to the Baseline scenario[9] (see Fig. 1). The BLUE Map scenario represents a tough challenge as it ‘requires unprecedented and far-reaching new policies in the energy sector’ (IEA 2008: 38). Generally, governmental energy policies are focused on several objectives which often compete: long-term security of supply, affordability, minimized impact on the environment *inter alia*. A change in government policies towards an environmentally acceptable, secure and affordable energy supply will certainly face opposition of economic interest groups as it occasions high economic costs. According to the IEA scenario analysis, additional investments in the range of 45 trillion USD until 2050 in R&D[10], larger deployment investment in technologies not yet market-competitive and commercial investment in low-carbon options will be needed when targeting the BLUE Map scenario. This equals to 1.1% of global GDP each year from now until 2050 (IEA 2008).

In order to reach the BLUE Map emission reduction target, the ‘deployment of all technologies involving marginal abatement costs[11] of up to USD 200 per tonne of CO_2 saved’ is required (IEA 2008: 39). Based on that condition, GHG abatement by investing in renewable energy technologies will become necessary and even cost-efficient. As shown in Fig. 1, renewable energy supply accounts for 17% of total abatement in the BLUE Map scenario. Since the costs as well as social and environmental barriers restrict the required growth of renewable energy technologies (RETs[12]), substantial supportive government policies are inevitable in order to reach an abatement share of 17% (IPCC 2007). The issue of RET promotion will be discussed in greater detail in the next subsections.

3.2 Role of renewables within the Swiss electricity supply

In order to establish a relation of potentials of renewable electricity generation technologies in Switzerland, the results of a survey (Infras/TNC 2010) can be considered. Today, Swiss electricity production is mainly based on hydropower (55.8% of total production) and nuclear power (39.3% of total production) (BFE 2010b). The share of electricity produced by plants recorded in the com-

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[8] The BLUE Map scenario assumes global GHG emission reductions 50 – 85% from current levels in order to ‘confine global warming to between 2°C and 2.4°C’ (IEA 2008: 38).

[9] The ‚business-as-usual‘ Baseline scenario assumes the absence of policy change and major supply constraints (IEA 2008). Following IPCC, a CO_2 emission development of this magnitude could raise global average temperatures by 6°C.

[10] ‚Research and Development’.

[11] Marginal abatement costs are the costs of reducing one additional entity of CO_2 emissions. Obviously, marginal abatement costs increase with increasing aggregated CO_2 abatement activities (see Field and Field 2006: 92).

[12] In the context of this study, technologies covered by the term ‘RETs’ refer to the definition used in the Swiss Energy Act (wind, solar, biomass, hydropower <10kWp, geothermal).

pensatory feed-in remuneration system KEV has reached 0.7% of total electricity production in 2009 (BFE 2010a). These figures raise the question whether the promotion of renewables will substantially increase the share of renewable electricity in the foreseeable future or not.

According to swisselectric[13], electricity prices will substantially increase within the coming 25 years due to increasing electricity consumption and decreasing installed capacity[14]. As a consequence, high investments in the extension of production capacity are needed within the coming decades. Infras (2010) compared the two investment scenarios 'large power plant' on the one hand and 'energy efficiency and renewable energy sources' on the other hand. The latter is divided into the options 'investments in renewables abroad' and 'domestic investments'. Infras provides evidence for the economic and technical feasibility of the scenario 'domestic investments'. This scenario considers only domestic investments in efficiency measures and renewable electricity production.

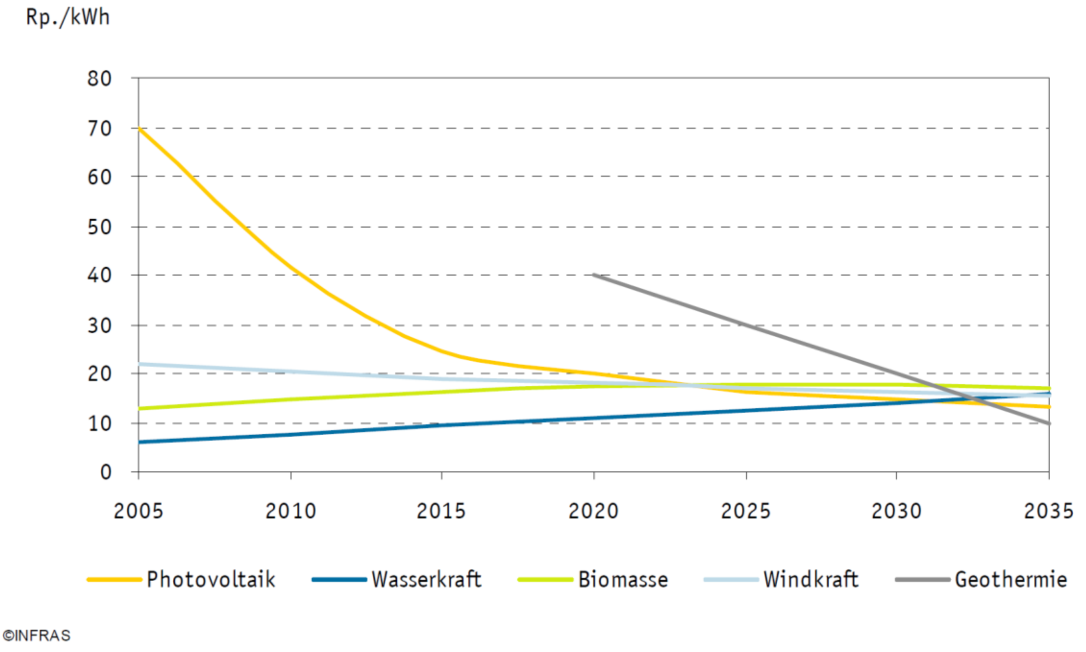

Fig. 2: Development scenarios of actual production costs for different renewable electricity production technologies (Infras/TNC 2010: 96).

Following Infras, total investments of CHF 65 billion would induce an energetic effect of 30TWh/a by 2035, of which efficiency measures account for 19TWh and renewable electricity production for 11TWh (Infras/TNC 2010: 99). Thus, the option 'domestic investments' can be a practicable way to avoid projected increase in electricity prices. The assumptions being subject to the option 'domestic investments' assign a great potential to the photovoltaic power production. By 2035, 4.5TWh of additional electric output per year [15] from PV production are being expected. This equals to a

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[13] swisselectric is the national lobby of electricity generators Alpiq, Axpo, BKW, CKW and EGL.

[14] swisselectric projects a so-called 'electricity supply gap' of 25 to 30TWh per year that will appear in Switzerland by 2035 based on an assumed increase in demand and decrease in supply. In economic terms, a 'supply gap' equals to an increase in market prices.

[15] This value refers to the installed capacity of 2005. Furthermore, growth rates of 30% (until 2015), 25% (2015 to 2020), 15% (2020 to 2030) and 8% (2030 – 2035) are assumed.

share of 16% regarding the overall target of 30TWh/a. The important role of PV technology must mainly be explained by assumed learning rates, which would lead to a decrease of current production costs by factor 5 until 2035 (see Fig. 2). With respect to the successful implementation of the option ‚domestic investments‘, it will be crucial whether the required policy measures are adopted in time and with an indispensable consistency. Much importance has to be attached to the removal of constraints and the promotion of renewable energy technologies (Infras/TNC 2010: 104/105).

Obviously, the theoretical potential of PV power production is significantly smaller in Switzerland compared to countries in southern Europe. Nevertheless, photovoltaic power production can play an important role within Swiss electricity supply if high investment volumes lead PV technology to commercialization stage and ensure its competitiveness on the market.

3.3 Rationale for promoting renewable electricity production

There is a broad scientific consensus[16] about the disability of renewable energy technologies to ‘greatly increase their market share over the next few decades without continued and sustained policy intervention’ (IPCC 2007: 272). The disability of RETs to reach market maturity independently can be explained by current low competitiveness, as well as appearing social and environmental costs. Among different RETs, photovoltaic (PV) power production is hit hardest by unfavorable conditions influencing actual costs. However, RETs are eligible for assistance. This may become plausible by investigating the reasons for the absence of competitiveness within the electricity supply sector in Switzerland.

From an economic point of view, the main reason for low competitiveness of PV electricity production is the presence of market failures. These are on the one hand external environmental costs[17] not being internalized, which lead to an energy mix biased in favor of fossil fuels (Kolev and Riess 2007). On the other hand, technological development is normally undersupplied on private markets since it is connected to external benefits (see 3.3.1). PV technology is currently at the deployment stage on its way to market maturity (see Fig. 3) where it needs support to overcome cost or non-cost barriers (IEA 2009). Following Field and Field (2006), market failures often call for public intervention and are hence a substantial rationale for promoting PV power production.

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[16] See broadly conceived studies developing energy demand and supply scenarios for the 21st century such as IEA World Energy Outlook (IEA 2009).

[17] Apart from private costs that show up in the profit-and-loss statement of firms, there is another type of cost that is external to the producer. Although these costs are real to some members of society, they don’t influence firm’s decisions about output rates. This can result in socially inefficient rates of output. External costs appear e.g. related to environmental damages that are caused by the emission of harmful substances such as SO_2 or greenhouse gases (Field and Field 2006: 69).

From an environmental point of view, renewable energy sources are able to occupy an important place in future low-carbon electricity supply (see subsection 3.3.2). Apart from mitigating GHG emissions, RETs also contribute to the prevention of other negative environmental effects such as SO_2 or PM10 emissions. In the context of this study, other effects apart from the abatement of greenhouse gas emissions will not be discussed. Finally, the support of renewable energy technologies induces several positive side effects which increase the equivalent value of promotion. These are namely the positive effects on the export sector of a country, employment and regional development (Finon 2007: 114). Such side effects will not be discussed in more detail in the context of this study.

3.3.1 Economic legitimation

Economists always seek for situations in which a market system, left to itself, produces a socially efficient[18] rate of output. At this rate of output, the aggregated benefit of all members of a society is maximized[19]. In reality, market systems normally suffer from market failures which lead to an inefficient allocation of resources. Market failures may justify public policy to help move the economy toward efficiency (Field and Field 2006; Stephan and Ahlheim 1996). Private electricity markets are affected by several kinds of market failures. Two of them are of particular importance in the context of promoting RETs and will be discussed in more detail: external environmental costs and external benefits of technological development.

External environmental costs

In order to enable socially efficient rates of output, the ‘marginal costs of production need to include all the costs of production such as external costs’ (Field and Field 2006: 65). In the case of air pollution control, a socially efficient allocation of resources requires a balance between abatement and damages (external costs). A policy that leads to the situation where marginal abatement costs equal marginal damages might provide an efficient allocation (Field and Field 2006: 180). In many cases, external environmental costs are either not internalized at all, or there are substantial differences between market values and social values of environmental resources. This leads to the condition that external costs don’t influence private decision making, resulting in a situation where ‘the use of a resource is likely to exceed its social optimum’ (Kolev and Riess 2007:135). With respect to energy supply markets, external environmental costs have a market-distorting impact in favor of fossil fuels and against renewable energy sources.

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[18] In this context, ‘socially efficient’ corresponds to a state in which total marginal production costs equal total willingness to pay of a society as a whole (Field and Field 2006: 64).

[19] This state corresponds to an allocation which is defined as "Pareto-efficient" as no changes to another allocation makes at least one individual better off without making any other individual worse off (Stephan and Ahlheim 1996).

From an economic point of view, there are different options to internalize external environmental costs. Imposing a tax on GHG emissions may be the first-best option inducing two main effects. Firstly, a static effect creating an incentive for abatement of emissions as a price on emissions acts as a penalty on pollution. Secondly, a dynamic effect leading to a decrease in abatement costs as abatement technologies are promoted (see Kolev and Riess 2007: 137). Both effects raise the production of renewable electricity. Due to the static effect, prices of clean energy sources decrease relative to the cost of fossil fuels, while the dynamic effect holds out additional economic rents for producers of renewable electricity as their costs may decrease.

Expectedly, the internalization of external effects is connected with number of difficulties. According to IEA (2008: 244), energy markets ‘generally fail to properly value the environmental benefits of clean energy technologies without regulatory interventions’. This refers to the major challenge of internalizing external costs: monetarizing the economic and social values of environmental benefits and burdens. The assessment of climate change impacts and damages turn out to be particularly difficult as the impacts will mainly appear in remote future (IPCC 2007). Thus, putting a fair price on GHG emissions is inevitably connected to high uncertainties. These uncertainties are often abused by policymakers to rather underestimate the values of environmental benefits and burdens in order to avoid high charges for the local business location (Finon 2007).

In sum, renewable energy sources are regularly faced with market disadvantages due to external environmental costs which are not (fully) internalized. With a view to high actual costs of PV produced electricity, the internalization of external costs will certainly not remove the current disability of PV technology to compete economically.

External benefits of technological development

New inventions and technological developments have some properties in common with public goods. A public good becomes, if made available to one person, automatically available to others. This may also be true for the external benefits of technological progress such as learning and experience. Private markets do normally undersupply such goods as ‘market players have the incentive to free ride[20] on the efforts of others’ (Field and Field 2006: 80). As a result, the supplier has difficulties to cover his costs due to reduced revenues[21] (Kolev and Riess 2007). Therefore, public goods are often provided by nonmarket institutions such as public authorities.

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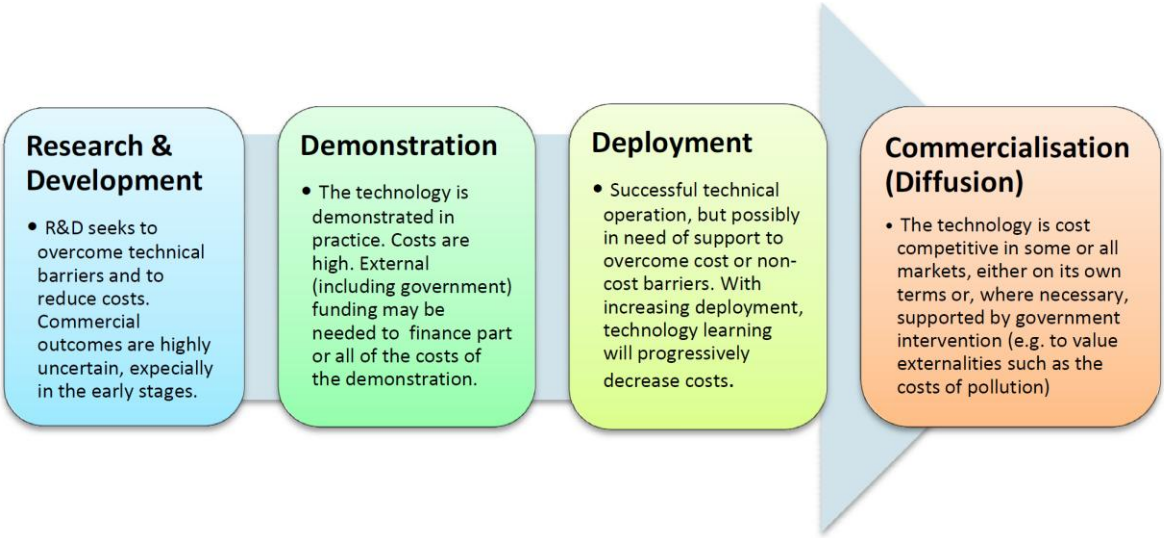
[20] ‘A free rider is a person who pays less for a good than her or his true marginal willingness to pay, that is, a person who underpays relative to the benefits he receives’ (Field and Field 2006: 80).

[21] Benefits that are not reflected in the price of a good are called ‘external’, as they appear external to the supplier of the good. Thus, suppliers of goods with external benefits will have reduced revenues totaling the value of external benefits.

Technological progress is faced with ‘market failures and externalities, which might prevent learning and experience to go as far as it should from society’s viewpoint’ (Kolev and Riess 2007: 135). In order to move towards a market equilibrium that is socially efficient, public support in favor of new technologies is economically desirable. Finon (2007: 113) points out that the ‘choice of the policy instrument needs to reflect at what stage the development of a renewable technology is’. The four development stages are illustrated in Fig. 3.



Research & Development

- R&D seeks to overcome technical barriers and to reduce costs. Commercial outcomes are highly uncertain, expecially in the early stages.

Demonstration

- The technology is demonstrated in practice. Costs are high. External (including government) funding may be needed to finance part or all of the costs of the demonstration.

Deployment

- Successful technical operation, but possibly in need of support to overcome cost or non-cost barriers. With increasing deployment, technology learning will progressively decrease costs.

Commercialisation (Diffusion)

- The technology is cost competitive in some or all markets, either on its own terms or, where necessary, supported by government intervention (e.g. to value externalities such as the costs of pollution)

Fig. 3: Stages in technology development. New technologies typically go through several stages to overcome technical and cost barriers before becoming cost-competitive (corresponding to IEA 2008: 202).

To date, investment grants turned out to be most effective if a technology can be allocated to R&D or demonstration stage. During deployment stage, subsidizing the production provides an incentive to run installations with high output efficiency. The commercialization stage is characterized by full reliance on the energy price effect of internalizing external environmental costs of fossil fuels (Finon 2007: 113). Based on so called ‘learning curves’ describing the relation between specific investment costs and cumulative installed capacity, deployment costs[22] of new technologies can be estimated. Learning curves represent a ‘constant reduction of the investment costs for each doubling of production’ (IEA 2008: 203). Fig. 4 shows that learning investments lead to a decrease in costs of new technologies until the costs equal those of cost-competitive technologies at the break-even point. Furthermore, it becomes obvious that increasing CO_2 prices due to internalization of external costs reduce the learning investment needed to make the new technology cost-competitive (IEA 2008: 204). PV power production technology has currently reached the deployment stage and is hence in need of support to overcome cost or non-cost barriers.

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[22] Deployment costs equal to the total amount which must be invested in cumulative capacity to reach the break-even point (IEA 2008: 204).

Following IEA (2008: 143), ‘sustained and effective incentives are needed within the next 5 – 10 years to overcome the precompetitive stage of PV systems’. Based on the assumptions of the ‘Blue Map scenario’, the IEA predicts a decrease in actual costs of PV produced electricity to a competitive level in the range of 8 to 18 cents per kWh[23] by 2050.

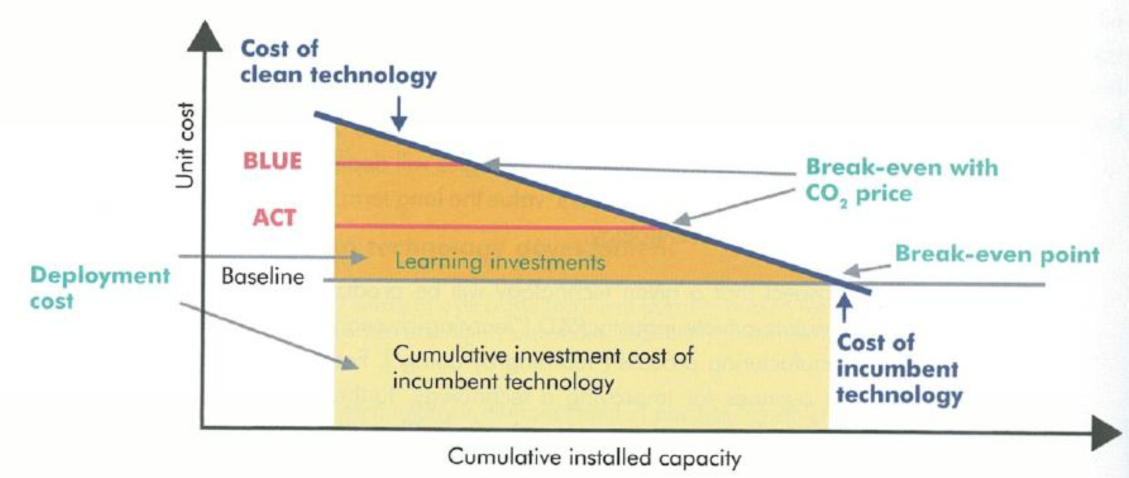

Fig. 4: Schematic representation of learning curves, deployment costs and learning investments (IEA 2008: 204).

But will PV power production ever reach market maturity? Following Kolev & Riess (2007: 135), there are justified reasons to assume that PV produced electricity will become economically competitive for several reasons. Firstly, external environmental costs of fossil fuels will rise over time and thereby decrease relative costs of electricity from renewables. Secondly, costs of mature RETs such as offshore wind power will increase as the quality of available locations worsens. Finally, the costs of new technologies will be lowered through technology learning. Currently, learning rates of around 20%[24] for the coming years are to be expected in the field of PV technology.

3.3.2 Environmental legitimation

In theory, removing all market failures by appropriate policy interventions would be a sufficient measure to ensure an optimal allocation of resources. The circumstance that perfect markets do not exist in reality legitimates direct policy interventions which target at specific goals, e.g. the reduction of air pollution. In the field of RES promotion, environmental benefits of renewable energy sources belong to the main drivers for the support of the sector (van Dijk et al. 2003). Constraining on the electricity supply markets, the promotion of renewable electricity production is environmentally reasonable from different positions. Firstly, a long-term secure and clean electricity supply is

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[23] The high range of actual costs can be explained by differing preconditions in terms of global irradiation at different locations. By 2050, actual costs in the range of 11 to 13 cents per kWh are predicted for central Europe assuming an annual specific yield of almost 1000kWh per kWh (IEA 2008: 375).

[24] See IEA (2008), 203.

of fundamental importance with regard to the electrification process[25]. Secondly, renewable electricity production directly contributes to the mitigation of GHG emissions by replacing CO_2-intensive power plant capacity. Hereafter, these two aspects will be discussed in more detail.

The substitution of fossil fuels by electric applications (e.g. in the field of electric mobility) leads to a growing demand for electricity. This so called ‘electrification process’ induces a reduction of fossil fuel combustion and GHG emissions, but only if additional electricity demand is covered by clean electricity production. Hence, the current intensive development of electric applications has to be attended by the development of clean electricity production technologies in order to serve its purpose.

A rapid transition of the consisting electricity supply system towards a sustainable system with reduced carbon intensity is an essential precondition for many countries to achieve their CO_2 mitigation targets. On a global scale, the GHG emission reduction potential of the electricity sector ranges between 2.0 and 4.2 $GtCO_2$-eq. per year until 2030 which can be explained by the high share of coal and natural gas power production. According to IPCC (2007: 294), this mitigation potential may be exploited by increasing plant conversion efficiencies and the intensified use of low-carbon technologies such as RETs.

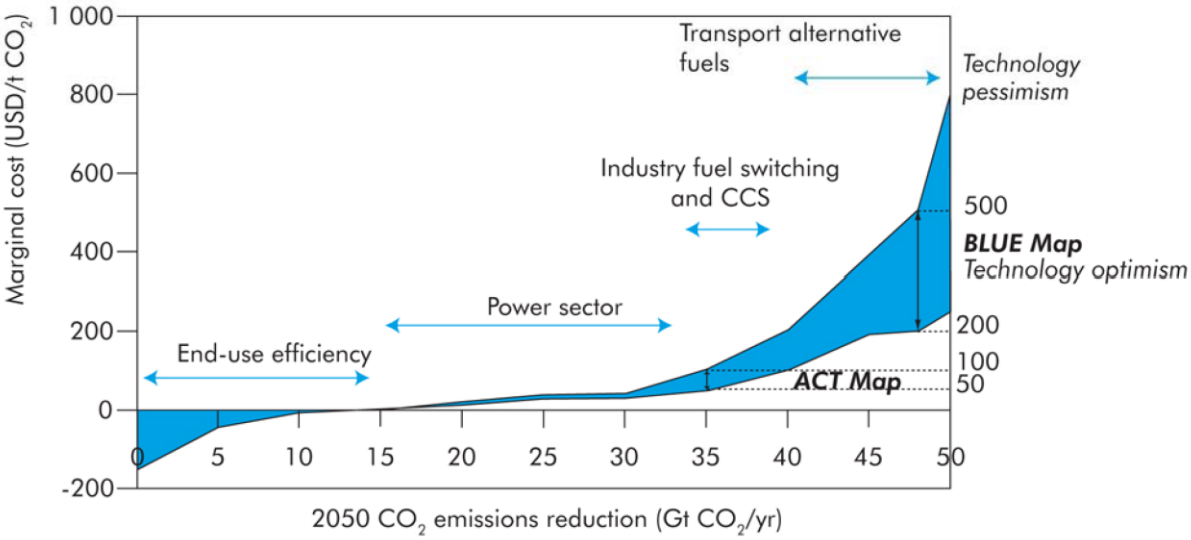

Fig. 5: Marginal emission reduction costs for the global energy system by 2050 (IEA 2008: 39).

If GHG mitigation is employed to justify RET promotion, it needs to fulfill the criterion of cost-efficiency in order to be economically desirable. This implies the prior exploitation of cheapest mitigation potentials. When focusing on photovoltaic power production, CO_2 abatement seems to be inefficient at first appearance as marginal abatement costs for CO_2 are significantly higher com-

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[25] Substitution of fossil fuel usage by electric applications as a consequence of enhanced GHG mitigation efforts.

pared to other abatement techniques[26]. When involving the scenario calculations of IEA (2008), the proportions change fundamentally. Based on the assumptions of BLUE Map scenario (limiting global warming to 2.0 – 2.4°C), Fig. 5 shows marginal emission reduction costs as a function of total CO_2 emission reductions. Accordingly, the deployment of all technologies involving mitigation costs up to USD 200 per tonne of CO_2-eq. saved (when the technology is fully commercialized) is required (IEA 2008: 39). Thus, even PV power production may become an economically efficient mitigation technology if mitigation efforts were dramatically enhanced.

However, PV power production is currently still a cost-inefficient way to mitigate GHG emissions. But, as demonstrated in subsection 3.3, the mitigation effect of PV power production is a valuable side effect of promoting this technology – even though it is not yet a sufficient rationale for governments to promote PV power generation.

3.3.3 Conclusions regarding rationale for RET promotion

Serious market failures, namely external environmental costs and external benefits, cause an undersupply of electricity from renewable energy sources. This calls for public interventions in order to move the market system towards a socially more efficient market situation. A practicable way to tackle market failures can be the internalization of external costs and benefits, e.g. by imposing a tax on GHG emissions or by directly subsidizing the development of renewable energy technologies. Internalizing external effects is nevertheless connected to substantial difficulties as the monetarization of external effects is connected to high uncertainties (Finon 2007). As a consequence, second-best options such as production based remuneration systems for RETs may become more attractive although they rather suffer of cost-ineffectiveness at first appearance. ‘By tackling not only environmental problems but also technology externalities’ and supply insecurity, such promotion systems kill two birds with one stone (Kolev and Riess 2007: 136). Thus, their cost-effectiveness may be higher than it first appears.

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[26] The abatement costs of CO2 vary according to local conditions and lie in the range of 60 to 250 US$/tCO2-eq. (IPCC 2007).

3.4 Objectives of promoting renewables in Switzerland

Policies promoting renewable energy sources are often directed to attain a bunch of short- and long-term objectives. The objectives may be assigned to different policy fields and compete sometimes. Accordingly, it is valuable to analyze and sort different levels of objectives that are of interest in the context of this study.

Referring to the Energy Act, Swiss energy policy is characterized by three superior objectives: securing of an economic, environmentally-compatible, secure and diversified supply[27]. The promotion of renewables is often directed to the same targets and contributes to their achievement on various levels and time scales (Voss 2000: 17).

Technology development: Energy technologies need to be competitive on the market and thereby affordable for consumers. Currently, renewable electricity production is not yet competitive. In order to reach the stage of commercial maturity, development and innovation processes have to be initiated in the field of RETs, for instance by subsidizing the production process (Finon 2007).

Environmental compatibility: This issue refers to a number of environmental externalities from energy production, mainly caused by fossil fuel burning. These are namely the emission of nitrogen oxide (NO_x), sulphur oxide (SO_2) and carbon dioxide (CO_2) *inter alia*, causing substantial external costs (IPCC 2007: 290). The substitution of fossil fuels by renewable energy sources leads to an environmentally more compatible energy supply.

Secure and diversified supply: As discussed in subsection 3.2, renewable electricity production may substantially contribute to a long-term and secure electricity supply in Switzerland. Moreover, the promotion of several RETs ensures a diversified power generation mix.

Apart of these superior objectives, the promotion of RETs induces several co-benefits such as the creation of local employment, a positive impact on social cohesion (European Commission 2001) or local benefits of GHG mitigation (IPCC 2007: 310). The most important objective of supporting RETs is certainly the technology development to the stage of commercial maturity. Once a technology is competitive, it will establish oneself on the market and thereby contribute to the attainment of other targets mentioned above. Based on politically defined objectives, a suitable promotion scheme has to be developed that covers the bunch of targets. From an economic point of view, the objectives need to be attained in a cost-effective way. This issue is an important subject of this study and will be discussed in more detail.

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[27] Swiss Energy Act (EnG), Art. 1, paragraph 1

3.5 Feed-in remuneration scheme

After providing evidence for the need of public support for RET development and deployment, the appropriateness of supporting systems has to be evaluated. Different supporting schemes and their (dis)advantages allowing for various framework conditions have been extensively investigated (Finon 2007; Haas et al. 2004; Held 2007; van Dijk et al. 2003) and will not be discussed in great detail here. Rather, the Swiss supporting scheme KEV will be assessed and classified within the wide range of supporting systems.

When considering the various objectives the Swiss supporting system has to attain, a basic question arises: Would it be more effective to reach single targets by adopting several instruments specifically adjusted to tackle particular market failures? Or shall a policy be directed to aim several targets at once?

Whether it is most effective or not, the Swiss legislator decided for the latter and adopted a regulatory, price-driven feed-in remuneration system that pursues several targets at once. Feed-in tariffs have been adopted in most European countries and prove itself in practice. Nevertheless, such policies need to be regionally specific ‘taking into account the development stage and other characteristics of the technology, actors and structure of the renewable energy market, the availability of budgets and the policy context’ (van Dijk et al. 2003: 46). Even more important may be their flexibility to adapt to changing surrounding conditions. In the following, supporting system properties, quality criteria and occurring problems are shortly described.

3.5.1 Classification of feed-in tariffs within various supporting systems

Fig. 6 provides an overview on most important promotion policies in the field of renewable. Policy measures promoting renewable electricity production do either directly stimulate the production of electricity or indirectly by removing barriers to progress. Among direct policy measures, a further distinction can be made between price-driven and quantity-driven systems[28]. A final differentiation concerns the targeted stage of the value chain, as the support may either be focused on investment or on generation (see Fig. 6). Feed-in tariffs are direct, price-driven, generation based incentives on a regulatory basis.

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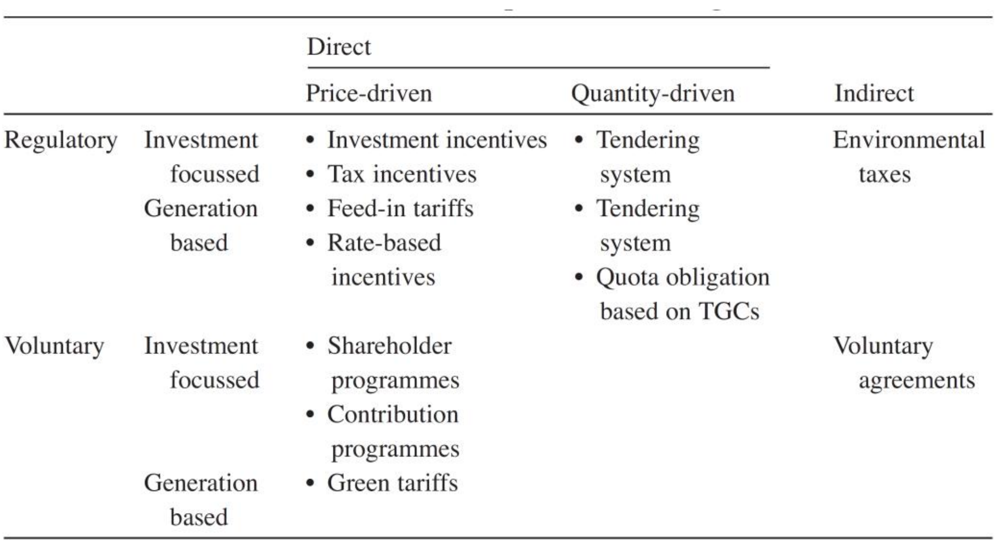
[28] While price-driven systems provide financial incentives to invest in RETs, quantity-driven systems aim to reach a target by quantity obligations and enforcement strategies in case of non-compliance (van Dijk et al. 2003).



		Direct		
		Price-driven	Quantity-driven	Indirect
Regulatory	Investment focussed	• Investment incentives • Tax incentives	• Tendering system	Environmental taxes
	Generation based	• Feed-in tariffs • Rate-based incentives	• Tendering system • Quota obligation based on TGCs	
Voluntary	Investment focussed	• Shareholder programmes • Contribution programmes		Voluntary agreements
	Generation based	• Green tariffs		

Fig. 6: Classification of promotion strategies (Held, Ragwitz and Haas 2006: 852).

3.5.2 Feed-in remuneration system properties

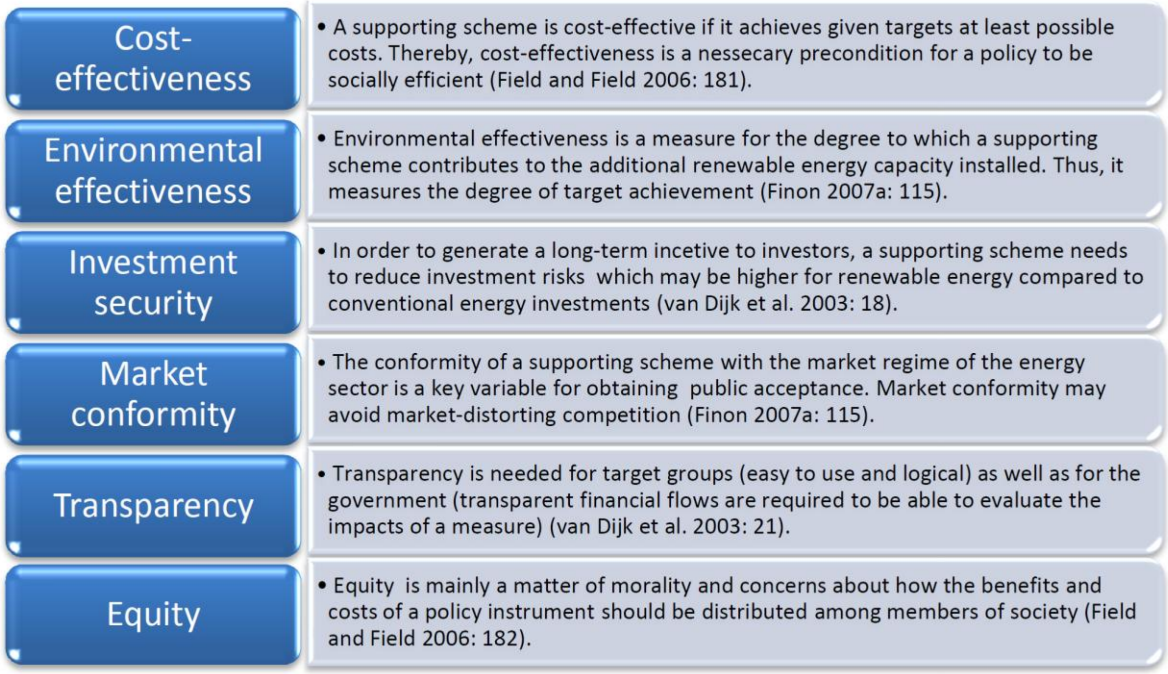
Any plant operator on the electricity market is legally authorized to feed-in the amount of electricity produced using renewable energy sources to the grid. A public authority compensates producers with a fixed tariff rate per unit of produced electricity over a guaranteed duration (Held et al. 2006). The financing of the support is usually ensured by a tax on electricity consumption. Feed-in remuneration schemes imply the following system characteristics:

- Technology-specific promotion rates are possible.
- Tariff rates may consecutively be adapted to changing framework conditions, namely to interest rate volatility and cost reductions due to technology learning.
- Guaranteed duration of promotion implies the risk of miscalculating the operational lifespan.
- As tariff rates are normally homogenous for greater regions or even whole countries, site-specific aspects determining output or costs are often not considered adequately.
- A continual incentive to maximize the output may increase the quality of installed capacity and ensure investments in plant maintenance.
- Low transaction costs.
- Strong incentives to prefer productive and suitable locations not causing extra costs such as roof rents or grid amplifications.

These characteristics determine to some extent the quality and overall performance of the supporting scheme. Accordingly, they will be of basic importance when assessing the Swiss supporting scheme KEV.

3.5.3 Quality assessment criteria

In order to move the renewable energy market towards a socially efficient state of affairs, a supporting scheme has to fulfill a range of criteria concerning various fields of social relevance. A fundamental precondition for social efficiency is the setting of appropriate targets. Given the right targets, the following quality criteria have to be considered when designing a promotion policy (see Table 1).



Cost-effectiveness	• A supporting scheme is cost-effective if it achieves given targets at least possible costs. Thereby, cost-effectiveness is a nessecary precondition for a policy to be socially efficient (Field and Field 2006: 181).
Environmental effectiveness	• Environmental effectiveness is a measure for the degree to which a supporting scheme contributes to the additional renewable energy capacity installed. Thus, it measures the degree of target achievement (Finon 2007a: 115).
Investment security	• In order to generate a long-term incetive to investors, a supporting scheme needs to reduce investment risks which may be higher for renewable energy compared to conventional energy investments (van Dijk et al. 2003: 18).
Market conformity	• The conformity of a supporting scheme with the market regime of the energy sector is a key variable for obtaining public acceptance. Market conformity may avoid market-distorting competition (Finon 2007a: 115).
Transparency	• Transparency is needed for target groups (easy to use and logical) as well as for the government (transparent financial flows are required to be able to evaluate the impacts of a measure) (van Dijk et al. 2003: 21).
Equity	• Equity is mainly a matter of morality and concerns about how the benefits and costs of a policy instrument should be distributed among members of society (Field and Field 2006: 182).

Table 1: Most important evaluation criteria for supporting schemes of renewable electricity production.

When designing or assessing renewable energy policies, a simple cost-benefit analysis will not meet the requirements of a holistic consideration. This may be affiliated to the presence of uncertainty about the value of environmental damages avoided, employment effects or other benefits connected to RET promotion (Finon 2007: 114). Therefore, it may be economically reasonable to apply cost-effectiveness as a primary policy criterion.

There is an important distinction to be highlighted between the terms ‘cost-effectiveness’ referring to a promotion system as a whole and ‘cost-efficiency’ referring to single economic entities recorded in a system. Cost-efficiency of a single plant refers to the comparison of actual production costs with the cost frontier, which represents the minimum production costs at a given output level (see Banfi and Filippini 2010). Hence, cost-efficiency is a measure for proximity to minimum production costs. Meanwhile, cost-effectiveness of a promotion system as a whole is a measure for proximity of average public support to minimum public support per unit of target achievement. If promotion system properties lead to a support level beyond the level of minimum support to reach the targets, cost-ineffectiveness appears.

3.5.4 Financial barriers for investors

As uncertainties are economic costs and thereby decisive barriers for investors, the reduction of risks belongs to the objectives of policies promoting RETs. In the field of photovoltaic power production, a well designed feed-in remuneration scheme may significantly reduce market risks of operation, but technical risks remain existent (European Commission 2003).

In general, investments in new technologies are connected to higher risks compared to mature technologies as long term empirical values are absent (IEA 2008). Among renewable energies, PV technology carries a very low market risk of operation as the share of variable costs is relatively low. In contrast, technical risks are considerable for PV technology, notably regarding the lifespan of PV modules and inverters as well as the degradation process of modules. Thus, the aggregated output over the entire lifespan of the plant as well as operation and maintenance costs carry substantial risks for investments in PV production.

With respect to the definition of feed-in tariff rates, the assessment of investment risks is of importance. The normal rate of return on equity set to calculate feed-in tariffs is composed of two fractions: the expected return on investment on the one hand and a risk premium on the other hand (Zweifel and Erdmann 2008). The risk premium should accordingly compensate the operator for investment risks.

3.5.5 Occurence of resource rents

Attributable to common properties of a feed-in remuneration system, the possibility of occurring resource rents (RR) is ubiquitous. Resource rents are defined as ‘the surplus return above the value of capital, labor, materials, and energy used to exploit a natural resource’ (Banfi and Filippini 2010: 2302). Such significant economic profits for investors may occur e.g. due to site-specific differences in costs or revenues. A resource rent determines economic profits, since feed-in remuneration already includes a normal rate of return[29]. Such economic profits are called ‘resource rents’ in the context of exploiting natural resources, e.g. in the field of renewable energy sources.

As will be described in subsection 4.1 and 4.2, there is a range of site-specific characteristics determining output and costs of PV power production. Namely the annual solar input and mean temperature varies significantly among locations leading to considerable differences in specific output quantities. Apart from that, special circumstances such as the necessity of grid amplification, scaffolding raise or reinforcement measures due to high amounts of snow may result in increasing investment costs. As a consequence of such site-specific characteristics, actual production costs per unit of output differ significantly. In the context of the Swiss feed-in remuneration system, only size

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[29] For instance, a normal rate of return of 5% on equity and debt capital is included in the feed-in tariffs of the Swiss promotion scheme KEV.

and type of plant determine the amount of remuneration per unit of output, while site-specific characteristics are disregarded. Hence, the difference between feed-in remuneration and actual production costs is charged to the plant operator.

Fig. 7 shows a market situation with ‘four producers operating in different regions with constant returns to scale’ (Banfi and Filippini 2010: 2304), differing only in average production costs. Marginal costs are assumed to equal average costs. Average costs include all capital costs, e.g. a fair rate of return on investments.

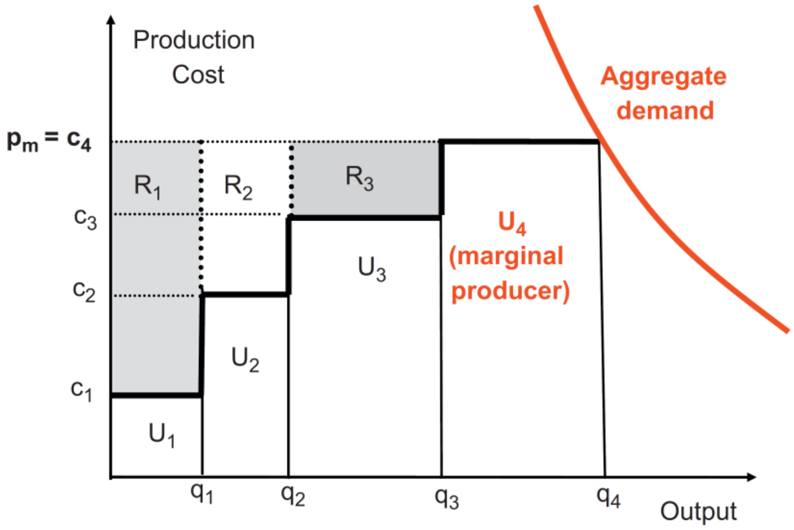

Fig. 7: Different producers and resource rent (Banfi and Filippini 2010: 2304).

U_4 is the marginal producer[30] whereas producers $U_1 – U_3$ have marginal costs ($c_1 – c_3$) below the feed-in tariff p_m[31]. A positive difference between p_m and U_x, defined as resource rent R_x, could be a sign of cost-ineffectiveness and thereby a quality failure of a RET promotion system, because the given output could be realized with less public funds. Such resource rents reflect the ‘true economic value of the natural resource exploited’ (Banfi and Filippini 2010: 2304), given a competitive market situation.

In order to move the market towards a social optimum, it is a legitimate concern of governments to avoid such resource rents as they are fiscal burdens to electricity consumers. Therefore, supporting systems need to be flexible and adaptable to spatially varying production conditions (Finon and Perez 2007). Within the design of the Swiss supporting system KEV, no mechanism avoiding resource rents is implemented. Several approaches to avoid resource rents come into question. Basically, a system change towards individual feed-in remuneration for each investor tailored on

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[30] For the marginal producer, the equation marginal costs = marginal revenue is valid (Mankiw 2009).
[31] In case of a feed-in remuneration system, p_m stands for the feed-in tariff as the market price on a competitive market would be far below production costs.

its actual production costs would be mandatory to exclude the possible appearance of economic profits. This could be achieved by applying a bidding procedure where investors offer their annual output to the national authority at a certain price per kWh. By admitting offers in the sequence of provided prices (beginning with lowest price), a supporting system can fulfill the criterion of cost-effectiveness (see van Dijk et al. 2003: 12). Such bidding procedures are connected to high uncertainties regarding quantitative target achievement. This can be explained by the existing incentive to offer at prices which do not cover the costs in order to get into the system. As a result of, a substantial share of projects will never be realized and implementation delays appear endangering the target achievement as the experience in the United Kingdom demonstrates (van Dijk et al. 2003: 27).

3.6 Swiss supporting system KEV

3.6.1 Initial position

The revised Swiss Energy Act stipulates that annual electricity production from renewable energies must be increased by at least 5.4 billion kilowatt hours by 2030. This equals to around 10% of current electricity consumption in Switzerland (BFE 2010b). The Energy Act contains a range of measures with the aim of supporting renewable energies and energy efficiency. With regard to the target achievement, the cost-covering remuneration system for renewable electricity (KEV) is the most important policy measure.

The compensatory feed-in remuneration enables producers of renewable electricity from hydro power (up to 10 MWp of installed capacity), photovoltaic energy, wind power, geothermal power and biomass energy to feed-in their electricity output to the Swiss electricity grid at fixed compensation rates (BFE 2008). These so called ‘feed-in tariffs’ are supposed to cover actual costs of production over the entire lifetime of the facility.

The feed-in remuneration system KEV triggered an enormous interest in renewable energy investments. By the end of 2009, 8894 plants have been recorded in the KEV. As the total cost ceiling for KEV has been reached in the beginning of 2009 already, only around 30% of the applications could be considered to date. Thus, 5681 registered projects were put on a waiting list (BFE 2010a).

3.6.2 Legal basis of KEV

The compensatory feed-in remuneration system KEV is legally based on the revised Energy Act (EnG[32]) and the corresponding Energy Ordinance (EnV[33]). The following legal surrounding conditions are of substantial importance for both the adoption of a feed-in remuneration system as well as the design of the system:

a. The EnG stipulates the securing of an economic and environmentally-compatible supply and distribution of energy as well as an increased use of domestic and renewable energy sources[34]. The term ‘environmentally-compatible’ is defined as a considerate exploitation of natural resources, the use of renewable energy sources and the avoidance of harmful effects on humans and nature[35].

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[32] Energiegesetz (EnG) vom 26. Juni 1998 (Stand am 1. Januar 2010), SR 730.0
[33] Energieverordnung (EnV) vom 7. Dezember 1998 (Stand 1. Januar 2010), SR 730.01
[34] EnG Art. 1, paragraph 2a and 2c
[35] EnG Art. 5, paragraph 3

b. Concerning the design of the feed-in remuneration system, the EnG stipulates cost-covering feed-in tariffs that are based on actual costs of reference facilities[36]. Relevant cost components are limited to compulsory required facilities for electricity production[37]. Feed-in tariffs remain constant over a predefined lifetime of the plant unless major changes of framework conditions appear[38].

The legal specifications mentioned in a. have major implications for the objectives of the Swiss feed-in remuneration system, while specifications b. affect the attainable cost-effectiveness considerably.

3.6.3 Properties of KEV in the field of photovoltaics[39]

Within the field of PV power production, feed-in tariffs are graduated according to the type and size of a plant. As defined in the Swiss Energy Ordinance (EnV), three basic types of plants are covered with increasing tariff rates in order of appearance: ground mounted, roof mounted and building integrated plants[40]. Moreover, the tariff rates decrease with growing installed capacity as a consequence of expected economies of scale. Finally, tariff rates decrease with time (8 % per year) as a consequence of technology learning. Table 2 shows tariff rates for the year 2009.

Feed-in tariff calculations are based on estimated investment costs of reference plants which vary with size and type of the plant[41]. Additionally, fixed maintenance costs of 8 cents per kWh are added, independently of size and type of the plant.

Performance category	Tariff rate ‘ground mounted’	Tariff rate ‘roof mounted’	Tariff rate ‘building integrated’
≤ 10 kWp	65 cents	75 cents	90 cents
≤ 30 kWp	54 cents	65 cents	74 cents
≤ 100 kWp	51 cents	62 cents	67 cents
> 100 kWp	49 cents	60 cents	62 cents

Table 2: Feed-in tariff rates in Swiss francs for the year 2009 according to the type and size of plant (Source: EnV, Annex 1.2)

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[36] EnG Art. 5, paragraph 2

[37] See Appendix 1.

[38] These are namely substantial changes of fuel prices, water interests or interests on capital (EnV Art. 3e)

[39] From now on, the scope of arguments will be narrowed to the field of renewable electricity production in Switzerland with a special focus on photovoltaic power production. In many cases, arguments are only valid under the specific circumstances of PV power production within Switzerland.

[40] See EnV, Annex 1.2, paragraph 2

[41] Annex I contains a list of predefined cost components that are considered for calculating the investment costs. This issue will be discussed in more detail in subsection 4.2.

According to the Swiss Energy Act, feed-in tariffs are supposed to cover actual costs of production. Under ordinary conditions, tariff rates are hold constant over the entire lifespan of a plant. Therefore, their setting prior to the initial starting-up of the plant implies a number of severe assumptions concerning output and costs:

Lifetime of PV plants:	25 years
Interest on capital:	5%
Specific output:	950 kWh / kWp and year
Maintenance costs:	8 cents/kWh

Starting from these assumptions, the tariff rate is deduced by applying an annuity method: first calculating the payment amount for a loan[42] (annuity) based on an interest rate and a constant payment schedule[43]. The annuity is then divided by the output, and a fixed maintenance surcharge of 8 cents per kWh is added:

$$Feed - in\ tariff = \frac{Annuity\ \left[\frac{CHF}{year}\right]}{Specific\ yield\ \left[\frac{kWh}{kWp * year}\right] \times Installed\ capacity\ [kWp]} + Maintenance\ [CHF/kWh]$$

The assumptions mentioned above are partly associated with high uncertainties. Empirical values related to the lifespan of PV plants, the specific output and the maintenance costs scarcely exist (Kaltschmitt, Müller and Schneider 2006a; Nowak, Gnos and Gutschner 2009). Hence, if real circumstances appear to differ significantly from the assumptions, the criterion ‘cost-covering’ may not be met. Additionally, cost-effectiveness and thus environmental effectiveness of the supporting system are subject to the adequacy of the assumptions.

3.6.4 Assessment of Swiss supporting scheme KEV

The KEV currently suffers from considerable implementation weaknesses, notably in the field of photovoltaic power production. Six month after it came into force, the system was already oversubscribed and could not be deblocked to date. The high number of potential investors which were put on a waiting list to be admitted into the system emphasizes the extent of the implementation delay (BFE 2009). The KEV provides in its current configuration strong incentives to invest in PV production capacity. Apart from strong incentives, legal regulations and implementation problems belong to the assignable causes of the long waiting list.

A system supporting renewable energy systems should provide investment security. As a result of the mentioned system blocking, the KEV does certainly not fulfill this condition currently. Moreover,

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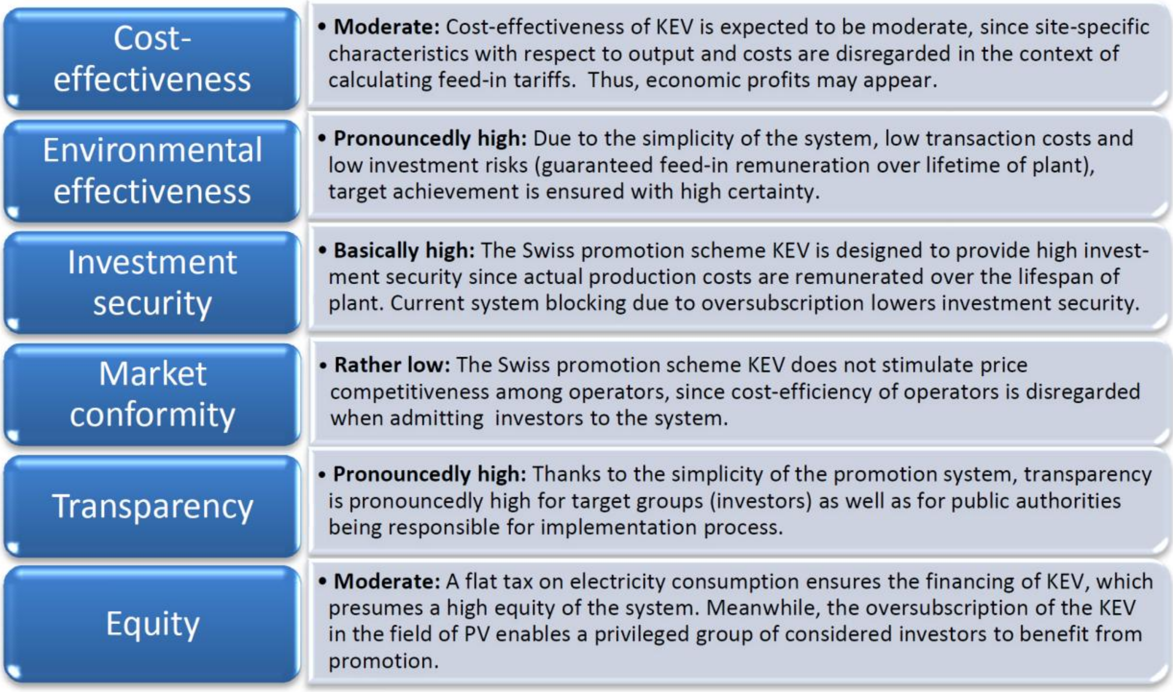
[42] The loan equals to the estimated investment costs which were calculated for reference plants.
[43] Known as the ‘annuity method’, it refers to the function ‚Pmt‘ in MS Excel.

the system blocking endangers the quantitative achievement of targets. Accordingly, possible system changes have to be reviewed. With regard to the mentioned oversubscription, the question of whether the KEV provides too strong incentives or not is certainly of relevance. As the Swiss supporting system disregards the possibility of resource rents (see subsection 3.5.5), cost-ineffectiveness in terms of economic profits above the value of capital likely appears. With respect to the legal percept of cost-covering feed-in remunerations, the Swiss supporting system should theoretically consider actual production costs of each single PV plant when defining the feed-in tariff. In the empirical part of this study, possible system ineffectiveness will be investigated and appearing resource rents quantified.

In order to provide a conclusive outline of the Swiss supporting system's properties, a qualitative assessment corresponding to the criteria applied in subsection 3.5.3 is presented in Table 3. Cost-effectiveness, market conformity and equity of the KEV are assessed to be moderate or low, while environmental effectiveness, investment security and transparency appear to be the strengths of the system.



Cost-effectiveness	• **Moderate:** Cost-effectiveness of KEV is expected to be moderate, since site-specific characteristics with respect to output and costs are disregarded in the context of calculating feed-in tariffs. Thus, economic profits may appear.
Environmental effectiveness	• **Pronouncedly high:** Due to the simplicity of the system, low transaction costs and low investment risks (guaranteed feed-in remuneration over lifetime of plant), target achievement is ensured with high certainty.
Investment security	• **Basically high:** The Swiss promotion scheme KEV is designed to provide high investment security since actual production costs are remunerated over the lifespan of plant. Current system blocking due to oversubscription lowers investment security.
Market conformity	• **Rather low:** The Swiss promotion scheme KEV does not stimulate price competitiveness among operators, since cost-efficiency of operators is disregarded when admitting investors to the system.
Transparency	• **Pronouncedly high:** Thanks to the simplicity of the promotion system, transparency is pronouncedly high for target groups (investors) as well as for public authorities being responsible for implementation process.
Equity	• **Moderate:** A flat tax on electricity consumption ensures the financing of KEV, which presumes a high equity of the system. Meanwhile, the oversubscription of the KEV in the field of PV enables a privileged group of considered investors to benefit from promotion.

Table 3: Qualitative assessment of Swiss supporting system KEV with respect to most important evaluation criteria (Source: compiled by the author).

4 Technology specific aspects of photovoltaic power production[44]

4.1 Factors determining output quantity

The basic component of a photovoltaic system is a PV cell which converts direct and diffuse irradiation to electricity. An electronic semiconductor enables photons to create free electrons in a PV cell converting solar energy into direct-current (DC) electricity (IEA 2008). Inverters transform the produced DC to grid-compatible alternating current (AC) inducing maximum losses of less than 10% (Seltmann 2009). There is a number of exogenous and endogenous[45] factors determining annual output of a PV cell. The primary output determinant is the total annual amount of energy reaching the modules. Apart from global irradiation which is external to the range of influence of operators, site-specific factors such as vegetation shadowing or technical features such as angle of tilt[46] and azimuth angle[47] are responsible for variations in total energy availability reaching the modules. Moreover, meteorological factors such as mean temperature affect the module performance. Depending on site-characteristics, some factors can induce contrary effects making it difficult to plot different geographic regions with respect to their appropriateness for PV power production. Altogether, there is certainly an ample scope for operators within planning and operation processes to influence the specific output of a plant.

In the following, a range of output determinants are described which are of relevance for the assessment of site-appropriateness. The list of selected determinants raises no claim to completeness.

4.1.1 Exogenous output determinants

Global irradiation

In central Europe, mean annual global irradiation accounts for around 1100kWh per square meter (Kaltschmitt and Streicher 2006). When looking at the variation of global irradiation in Switzerland, substantial differences with regard to the theoretical potential of PV power production appear (see

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[44] In section 4, the line of arguments will be constrained on aspects being of particular importance for roof-mounted PV systems since the empirical part of this study is limited to the investigation of roof-mounted systems.

[45] These terms refer to the theoretical range of influence of plant operators. In practice, some factors such as the angle of tilt turn out to be exogenous to the influence of investors as the inclination of their roof is given.

[46] The angle of tilt corresponds to the deviation of modules from the horizontal (Flimpex AG 2007).

[47] The deviation of module surfaces from the precise south alignment is specified by the so called azimuth angle. An azimuth angle of 0° implies a perfect south alignment, while 45° (south west) and – 45° (south east) respectively indicate a deviation from the optimum (Seltmann 2009).

Fig. 8). In practice, mean global irradiation does not say much about the effective solar input at individual locations since site-specific factors, e.g. the elevation of horizon, may reduce solar irradiation substantially.

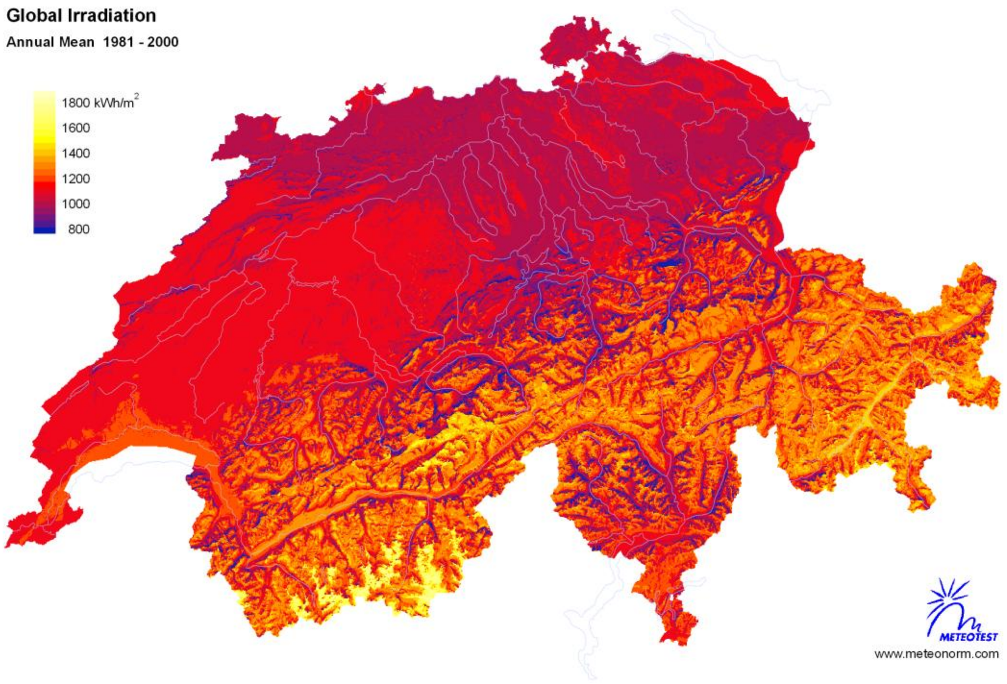

Fig. 8: Annual mean global irradiation impinging on a horizontal surface (Meteotest 2001).

Mean temperature and snow cover

The conversion efficiency factor of PV modules decreases with increasing cell temperature (Kaltschmitt et al. 2006b), which can be explained by physical properties of used materials. Accordingly, low mean ambient temperatures have a positive effect on the specific output of PV plants. In colder regions, a less powerful contrary effect is triggered in by a growing number of days where snow covers PV modules leading to a decrease in output. In sum, the specific output normally increases with altitude and decreasing mean temperatures (Seltmann 2009).

4.1.2 Endogenous output determinants

Azimuth angle and angle of tilt

The total amount of energy reaching the module surface is endogenously determined by the angle of tilt and the azimuth angle of the plant. Thus, an appropriate alignment of modules is a precondition in order to reach a satisfactory specific output. For central Europe, an angle of tilt of 30° and an azimuth angle of 0° are aligned perfectly. However, minor deviations from the optimum are not necessarily problematic, as a high percentage of possible output can be reached with suboptimal alignments (Seltmann 2009).

Dimensioning of inverter capacity

Inverters convert DC current produced by solar cells into grid-compatible AC current. The efficiency factor of an inverter depends on the load factor[48], which implies varying efficiency factors with changing weather conditions. Inverters normally work most efficiently with a load factor close to 1 (Kaltschmitt et al. 2006b: 233). As the share of diffuse radiation is high in central Europe, the output power is frequently significantly lower than the nominal power. Hence, the capacity of inverters should be smaller compared to nominal module capacity in order to maximize the output (Seltmann 2009)[49].

Frequency of maintenance

In principal, roof mounted PV power plants are low maintenance systems as no moving parts are involved (IEA 2008: 373). However, some output relevant factors are in the range of influence to operators. Firstly, the continual monitoring of proper operation avoids revenue losses in case of system failures. Secondly, the cleaning of module surfaces is occasionally required as polluted module surfaces decrease output significantly. Finally, removing the snow cover from PV module surfaces can be reasonable if the angle of tilt is shallow (<25°) which results in long-lasting snow cover (Seltmann 2009).

4.2 Factors determining total costs

4.2.1 Investment cost factors

Total investment costs for a PV production system are mainly composed of costs for PV modules, inverters, fixing, wiring and grid connection material and labor. Concerning these costs, economies of scale can be observed (Kaltschmitt, Streicher and Wiese 2006c). Expectedly, actual investment costs appearing at a given location depend on the site-specific characteristics such as the state of preservation of the building or the grid connection. The following factors may cause substantial extra costs, whereby the list of circumstances leading to varying investment costs could be endlessly extended (see Seltmann 2009):

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[48] The load factor equals to the ratio of output power and nominal power and lies between 0 and 1.

[49] There is a range of further technical factors such as the electric wiring determining system losses. These will not be discussed in more detail.

Grid amplification: Depending on the installed PV capacity, an amplification of the existing grid to the nearest transformer may be needed. In remote areas, e.g. on isolated farms, the nearest transformer may well be at a distance of one kilometer leading to additional costs of several ten thousand Swiss francs.

Lightening protection: The additional value of a building attributable to the PV system on its roof may call for a lightening protection for insuring reasons.

Scaffolding: Depending on the elevation of a building and the angle of tilt, the costs for scaffolding vary significantly.

In order to preferentially promote lower-cost sites, the legislator defined minimal investment requirements for PV power production (see Table 4). Feed-in tariff calculation is based on these minimal investment requirements. In avoidance of incomparability with feed-in tariffs of the Swiss supporting system, empirically observed investment costs within this study refer to minimal investment requirements listed in Table 4.

Cost category:	Containing the following cost factors:
Materials	PV modules, inverters, fixing materials, distribution board, switches, wires, basic lightening protection materials, monitoring system, transports
Labor	Planning, installation of subconstruction, installation of fixation system and modules, installation of inverters, installation of wiring DC / AC, grid connection, installation of monitoring system
Procurement costs	Fees for building permit, heavy current inspectorate (ESTI), proof of origin (HKN); facilities for construction site (elevator e.g.); finance charges

Table 4: Minimal investment requirements for PV power production according to EnV (Annex 1.2)

Costs of capital

The costs of capital in terms of interest rates on equity and debt capital represent a fundamental element when evaluating total investment costs. The weighted average cost of capital (WACC) is a commonly used approach to define the anticipated normal rate of return (Konstantin 2007: 152). It is basically composed of a risk-free interest rate and a risk add-on covering risks connected to the investment. The risk-free interest rate may be approximated by current interest rates of so called benchmark interest rates (e.g. government bonds), while the estimation of a risk add-on is characterized by high uncertainties (see Zweifel and Erdmann 2008). The weighted average rate of return is commonly used as discounting rate in calculations of profitability.

With regard to current renewable energy investments in Switzerland, a benchmark interest rate of around 3% may be assumed[50]. Meanwhile, fixing the risk surcharge is subject to a number of assumptions and, thereby, to high uncertainties. Factors such as capital intensity of a technology, lifespan of investment or expected variance of specific output have to be taken into account. According to Kaltschmitt (2006a), a rather low risk surcharge of 1.5% may be reasonable for PV technology. In the context of this study, a WACC of 5% is assumed in accordance with legally made assumptions (see Swiss Energy Ordinance and subsection 3.6.3).

4.2.2 Operation and maintenance costs

As PV systems do not include moving parts, the operation and maintenance costs are low and account for around 0.5% of capital investment per year (IEA 2008, 373). Even though this statement is basically correct, it is connected to high uncertainties which are attributable to the absence of empirical values. Notably the lifespan of system components such as PV modules, inverters *inter alia* are broadly unknown and hardly predictable.

According to the Swiss Energy Ordinance, the following cost components are of relevance for the calculation of operation and maintenance costs in the context of the KEV: leasing of grid connection and electric meter, service subscription and regular maintenance costs, provision of capital for replacement equipment (modules, inverters *inter alia*) and administration expenses such as insurance fees[51]. Based on this restriction, operation and maintenance costs were empirically investigated with regard to the fixing of feed-in tariffs for Switzerland (see Toggweiler et al. 2008). As direct empirical data is scarcely available, information provided by plant operators, market agents and experts was used for calculations. Operation and maintenance costs in the range of CHF 0.04 to 0.17 per kWh of produced output were estimated, whereby these figures indicate the existence of high uncertainties. Based on the study of Toggweiler et al. (2008), the SFOE defined operation and maintenance costs at a fixed amount of CHF 0.08 per kWh of produced electricity, independently of size and type of PV plant recorded in the KEV. In the context of the present study, these costs will be assumed as well, since no further information is available.

4.3 GHG balance of PV power production

As discussed in subsection 3.1, renewable energy sources have to contribute substantially to global GHG emission reductions if the BLUE Map scenario is targeted. When focusing on the

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[50] The average return of Swiss government bonds within the past 60 month is used to define the benchmark interest rate in the electricity sector (see Swiss Current Supply Ordinance StromVV).

[51] See Swiss Energy Ordinance, Appendix 1.2

Swiss energy sector and on PV technology, the question arises whether renewable energy sources may contribute a similar share to national reduction targets. As Swiss electricity generation is mainly based on hydro and nuclear power, current GHG intensity of the Swiss electricity mix is pronouncedly low[52] compared to GHG intensity of PV produced electricity (see subsection 4.3.1). Does this circumstance withdraw the legitimation of PV produced electricity with respect to GHG emission reduction targets?

4.3.1 Life cycle analysis (LCA) of PV power production

Today, the environmental impacts of energy technologies are commonly investigated by applying the life-cycle analysis framework. Thereby, the environmental inputs and outputs of a product or process from cradle to grave are considered (Fthenakis and Kim 2010: 1). On the basis of life-cycle analyses results, environmental aspects may be adequately considered within policy decision processes. Knowledge about technology-specific impacts on the environment is essential to assess the potential of a given technology. In the context of this study, only GHG emissions from PV electricity production are discussed while other PV induced environmental impacts such as NO_x, SO_x or CdTe emissions are disregarded.

Five major life-cycle stages of PV technology need to be taken into account: (1) production of raw materials, (2) their processing and purification, (3) the manufacture of modules and balance of system components, (4) the installation and use of the systems, and (5) their decommissioning and disposal or recycling (Fthenakis and Kim 2010: 3). When quantifying CO_2-eq. per kWh emitted in the course of PV power production, a fundamental difficulty appears. The GHG intensity of PV systems depends highly on the emission factors of electricity supply in countries where system components were produced[53]. Therefore, the true values of CO_2-eq. per kWh may substantially differ among systems installed in one country. Nevertheless, mean values from life-cycle analyses are useful benchmarks for estimating GHG intensities. Assuming average output conditions of central Europe, mean greenhouse-gas emissions from PV power production add up to 106g CO_2-eq./kWh (Mono-Si modules) and 90g CO_2-eq./kWh (Multi-Si modules) respectively[54] (Kaltschmitt et al. 2006a: 265). These results of a life-cycle analysis will be used as reference values for further discussions.

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[52] According to IEA (2010), GHG intensity of electricity accounts for around 2g CO2-eq./kWh (hydropower) and 5g CO2-eq./kWh (nuclear power).

[53] According to Fthenakis and Kim (2010), the GHG emission factor of average US electricity grid is around 40% higher than that of the Western European. Hence, system components produced in Europe show significantly lower GHG emission intensities.

[54] As the conversion efficiency, material usage, and production energy efficiency of silicon are improving rapidly, frequent updates of life-cycle analyses are required (Fthenakis and Kim 2010). Thus, these figures may not be transferred to current production processes.

4.3.2 PV within Swiss electricity supply mix

Based on the figures presented above, one could deduce that PV technology will not contribute to the achievement of GHG emission reduction targets of Switzerland. From a long term perspective, there are several arguments contradicting this statement.

- Firstly, GHG intensity of PV technology will decrease along with a decreasing CO_2 intensity of the electricity production mix in countries where components are produced.
- Secondly, the current Swiss power plant capacity is non-sustainable due to the high share of nuclear power. Accordingly, a substantial share of installed capacity has to be substituted by renewable capacity in the foreseeable future.
- Finally, GHG intensity of Swiss electricity consumption exceeds the intensity of generated electricity by far. This may be led back to extensive trading activities of Swiss power companies on European electricity markets. Considering a survey of TEP Energy (2009), a net annual amount of 5.7 megatons of CO_2 is imported to Switzerland due to cross-border current fluxes (TEP Energy 2009: 101). This corresponds to around 80 to 110g CO_2-eq. per kWh of consumed electricity. Thus, GHG intensity of PV produced electricity almost equals to the current intensity of electricity consumption.

In conclusion, it is safe to say that PV power production in Switzerland is reasonable from long term GHG emission reduction perspective.

5 Empirical study

5.1 Objectives and design

The Swiss feed-in remuneration system KEV has been subject to controversial political discussions due to a system blocking arising shortly after the system became applicable. The Swiss Federal Office of Energy (SFOE) composed a review (see BFE 2009) in order to reveal possible system deficiencies and to propose solutions to policymakers. The authors assign a high realization potential to PV plant capacity and an enormous demand for financial support in the field of photovoltaics.

Intuitively, an oversubscription of a promotion scheme indicates the existence of too strong incentives for investors and, as a consequence, cost-ineffectiveness. Beginning with this assumption, the present empirical study was designed to provide evidence for the existence of cost-ineffectiveness inherent in the system in terms of resource (see subsection 3.5.5). In order to reach the objectives of the empirical study, a cross-section analysis with an initial sample of 88 PV plants was designed. The selection of the initial sample relies on the application of three criteria described in subsection 5.2.1. Data was collected on the basis of a standardized questionnaire (see Annex 2) that was filled in by the operators in collaboration with the study author. After the extraction of non-responses and ineligibles, a net sample of 61 observations remained.

5.2 Data

The Swiss Federal Office of Energy (SFOE) acts as national authority implementing the Swiss Energy Act and thereby the Swiss promotion scheme for renewable energy sources KEV. As the Swiss Energy Ordinance stipulates a regular validation of feed-in tariffs, the SFOE takes a great interest in data collection related to power plants recorded in the KEV. Based on this starting position, the empirical data for the present study could be collected with the consent of the SFOE. Thereby, the data collection was simplified and quality of collected data was increased as selected plant operators could be forced to cooperate. The information initially provided by the SFOE included name, address and location of plant operators as well as altitude above sea level, installed capacity, date of installation and type of plant. The data used in this study was collected from March to June 2010.

5.2.1 Selection criteria

Out of the basic population of registered plants within the KEV, a sample of 88 plants was selected by applying three selection criteria: type of plant, installed capacity, and date of entry into service. These criteria were defined with regard to the subsequent data analysis and may thereby be justified.

Type of plant 'roof-mounted': This type of plant is supposed to have greatest realization potential in Switzerland as it is the cheapest plant type which does not cause extra space requirements. Moreover, by narrowing down the investigations to one type of plant, empirical results of the present study are expected to be more expressive.

Installed capacity ≥ 15kWp: According to the experience of the Swiss Federal Office of Energy, operators of small power plants are often not able to provide detailed information on their investment costs. In order to ensure a high quality of data, smallest plants <15kWp were not considered.

Date of entry into service 2006 - 2008: Plants which entered into service before 2006 are not accepted within the KEV, whereby the year 2006 represents the lower bound of the considered timeframe. Since a minimum of 12 month of production are needed to calculate actual costs of production, plants which entered into service after 2008 were not included.

5.2.2 Properties of investigated sample

Since the application of mentioned selection criteria reduced the basic population to an initial sample of 88 observations, no further criteria were considered[55]. In order to qualify the results of this study, certain restrictions due to sample properties have to be imposed. Firstly, a uniform geographical distribution of observations is certainly not given. Particularly the Southern Alps and the western part of the country are underrepresented (see Fig. 9). The geographical distribution shown in Fig. 9 is assumed to be representative for the basic population as none of the applied selection criteria bears obvious geographical reference[56]. Thus, the inhomogeneous geographical distribution is not expected to cause a systematic bias. Apart from geographical location, the altitude above sea level is of certain relevance for PV power production. A high fraction of observations is situated in the Swiss Midlands on an altitude of 400 to 600 meters above sea level. However, a substantial amount of observations is located in higher regions enabling to deduce possible dependences on altitude.

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[55] A net sample of at least 50 to 60 observations was targeted in order to provide reasonable requirements for a quantitative analysis.

[56] This assumption has not been empirically verified.

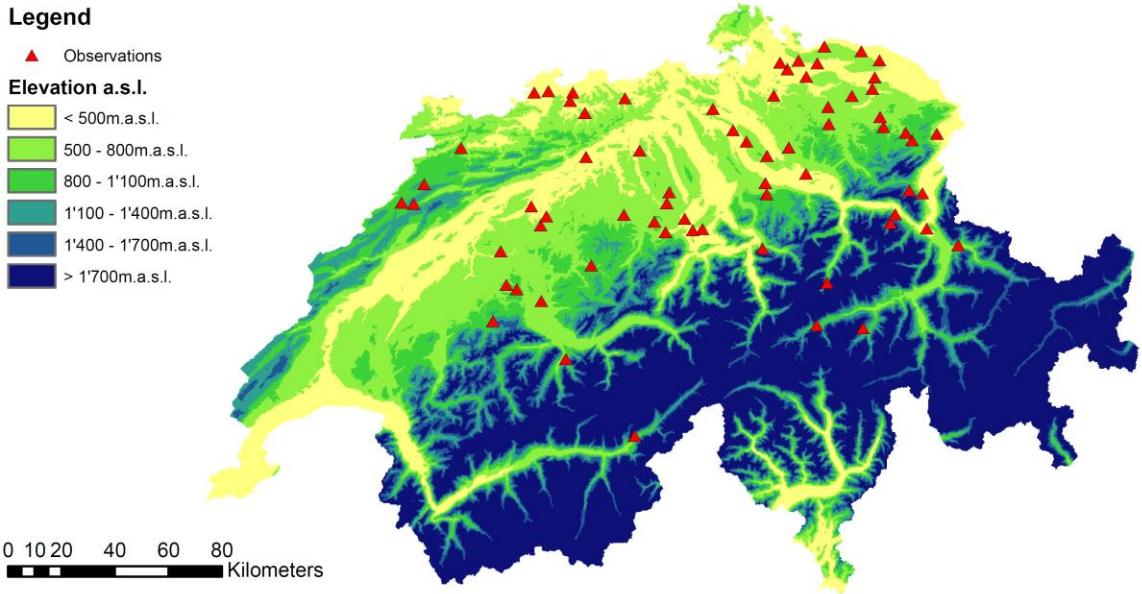

Fig. 9: Geographical distribution of the net sample within Switzerland (Source: compiled by the author).

Lastly, the distribution regarding installed plant capacity is of importance for any scaling dependencies such as economies of scale or returns to scale. Fig. 10 shows a high share of observations in the range of 15 to 30kWp installed capacity, while large capacities scarcely appear. Therefore, the deduction of scaling dependencies has to be handled with care.

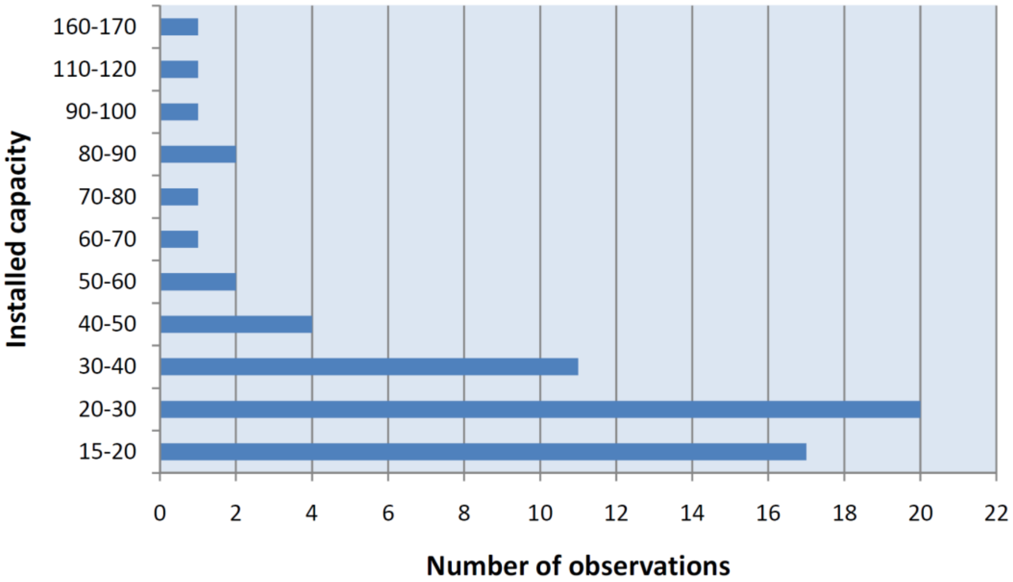

Fig. 10: Installed capacity of investigated PV power plants (Source: compiled by the author).

5.2.3 Data validation

The raw data collected in collaboration with plant operators had to be checked concerning its validity. Apart from mistakes appearing during data capture, another source of errors emerged. Due to incomparability of captured cost categories with categories in financial records of plant operators, the required invoice amount could not be deduced at the first attempt in some cases. As a consequence of existing sources of error, a three-stage validation process was defined: plausibility check, reexamination of outliers, and elimination of special cases (see Fig. 11).

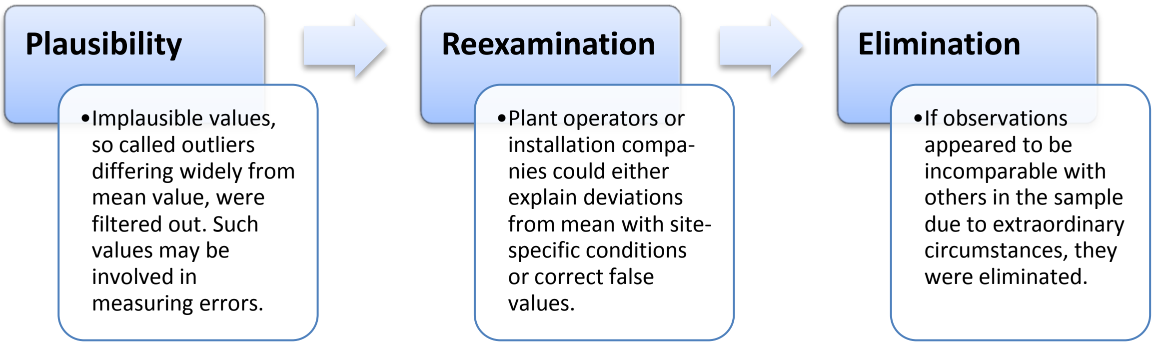

Fig. 11: Three-stage validation process applied on collected data (Source: compiled by the author).

In the context of data validation, totally four observations had to be eliminated due to incomparability with other observations. In all of these cases, fatal errors have been made in planning or realization of the PV plant leading to disproportional specific costs which would have biased the results of data analysis.

5.3 Methodological aspects

5.3.1 Ensuring plausibility of calculations

In order to make results of the empirical analysis plausible, some types of calculation and underlying assumptions are shortly described in this subsection.

PV power production: Regarding the output of PV plants, two scenarios were defined for the descriptive data analysis: ‘SFOE 950kWh’[57] scenario and ‘Output 2009’ scenario. The former is based on the assumptions made in the Swiss Energy Ordinance predicting a mean annual PV power production of 950kWh per kWp installed capacity. The latter refers to the effective power production of the year 2009. According to the latest state of the art in research, nominal power of

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[57] The ‘SFOE 950kWh’ scenario is a fictional scenario whereas the output assumption is in accordance with the legally assumed output level. It allows comparing the actual circumstance (‘Output 2009’ scenario) with legally assumed circumstances.

PV modules is assumed to degrade by about 0.5% per year[58]. Hence, the module degradation was considered to calculate mean annual production over 25 years of lifespan on the basis of total output produced in 2009[59]. This mean value will be used in scenario ‘Output 2009’, while a mean annual output of 950kWh per kWp is assumed in scenario ‘SFOE 950kWh’.

Actual costs: The calculation of actual production costs is based on the formula [1]. Thereby, maintenance costs are defined as an annual flat rate of CHF 76 per kWp of installed capacity which corresponds to the assumptions defined in the Swiss Energy Ordinance.

$$Actual\ costs\ = \frac{Total\ investment\ costs + Maintenance\ costs}{Aggregated\ output\ over\ lifetime}\ \left[\frac{CHF}{kWh}\right] \qquad [1]$$

Resource rent: As defined in subsection 3.5.5, the resource rent is calculated by subtracting actual production costs from feed-in remuneration which results in a (positive or negative) economic rent.

Inefficiently employed public funds: In order to get a feeling for the magnitude of inefficiently employed public means, the calculated resource rent of each PV plant is multiplied by the total amount of annual output.

5.4 Hypotheses

In the context of the present empirical investigation, two hypotheses are to be verified or falsified. Each of them is deduced from theoretical discussion in sections 3 and 4 of this study.

Hypothesis A:	A high variation in actual costs of PV produced electricity appears among operators of roof-mounted PV plants. Site-specific characteristics lead to varying total costs and to varying specific outputs (see subsection 4.1 and 4.2).
Hypothesis B:	A significant share of plant operators produces at costs below the fixed feed-in remuneration. Hence, system ineffectiveness in terms of resource rents appears (see subsection 3.5.5).

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[58] The magnitude of degradation is connected to high uncertainties and depends on various factors, e.g. the module type and processes of production (see Seltmann 2009 and Kaltschmitt 2006 for further discussion).

[59] It has to be stated that the calculation of projected mean output based on output quantities of the year 2009 is connected to substantial uncertainties. The specific output of PV plants changes from year to year due to changes in output determinants (global irradiation, mean temperature, snow cover, frequency of maintenance e.g., see section 4.1). But, as the influence of each determinant on the output may hardly be quantified and changes among locations, an adjustment of output values of 2009 to arithmetically averaged conditions appears to be impossible.

6 Results

6.1 Descriptive statistics

Indications for the existence of cost-ineffectiveness within the Swiss promotion scheme KEV can be deduced from descriptive statistical results. Thereby, the calculation of actual production costs and resource rents are in the focus of interest. In order to identify actual production costs, total costs are normalized by total output. This highlights the fundamental importance of making assumptions regarding the specific output quantity. As discussed in subsection 5.3, two output scenarios ('Output 2009' and 'SFOE 950kWh') are distinguished while other factors are held constant.

6.1.1 Specific investment costs

Specific investment costs are a useful indicator to assess the major share of PV power production costs and to classify PV installations which differ in size regarding their costs. The presented specific investment costs only cover minimum infrastructure investments necessary for photovoltaic power production as defined in the Swiss Energy Ordinance (see subsection 4.2 and Table 4).

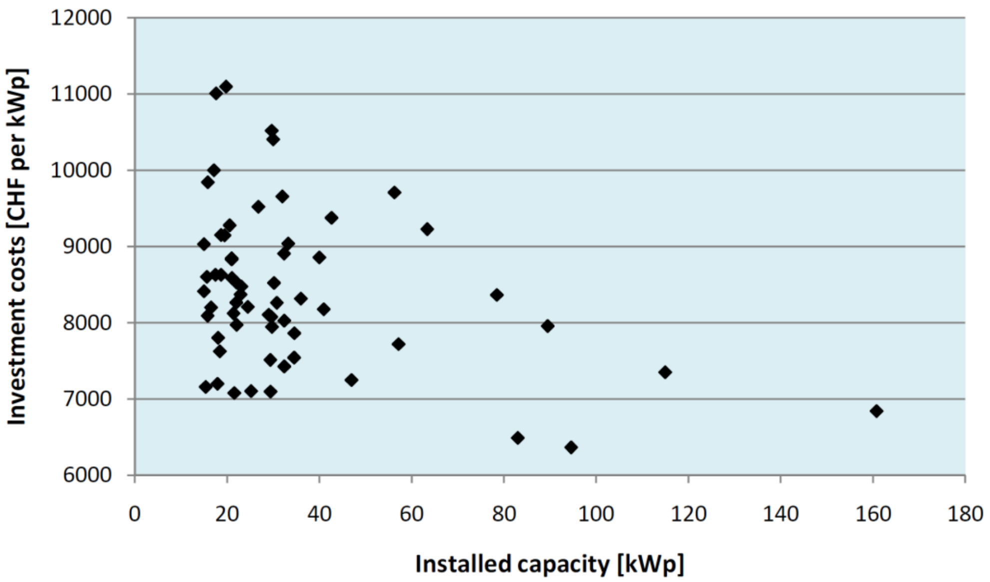

Fig. 12: Investment costs per unit of installed capacity (Source: compiled by the author).

In comparison with specific investment costs of reference plants, investment cost values shown in Fig. 12 appear to be plausible (see Kaltschmitt et al. 2006a: 262). The distribution of observations suggests that specific investment costs decrease significantly with increasing plant size. Moreover, a considerable variance is detectable among plants of the present sample. Notably plants with an installed capacity <40kWp show a pronounced heterogeneity. This may indicate the existence of market failures on the Swiss PV market, since a considerable potential to install PV capacity below the mean investment costs seems to exist. This is particularly true for smaller plants.

6.1.2 Specific output

The expected mean annual output shown in Fig. 13 was calculated based on the measured output of the year 2009[60] and an assumed module degradation of 0.5% per year over a lifespan of 25 years. The degradation leads to a projected mean output level lying 5.9% below the actually measured output values of 2009.

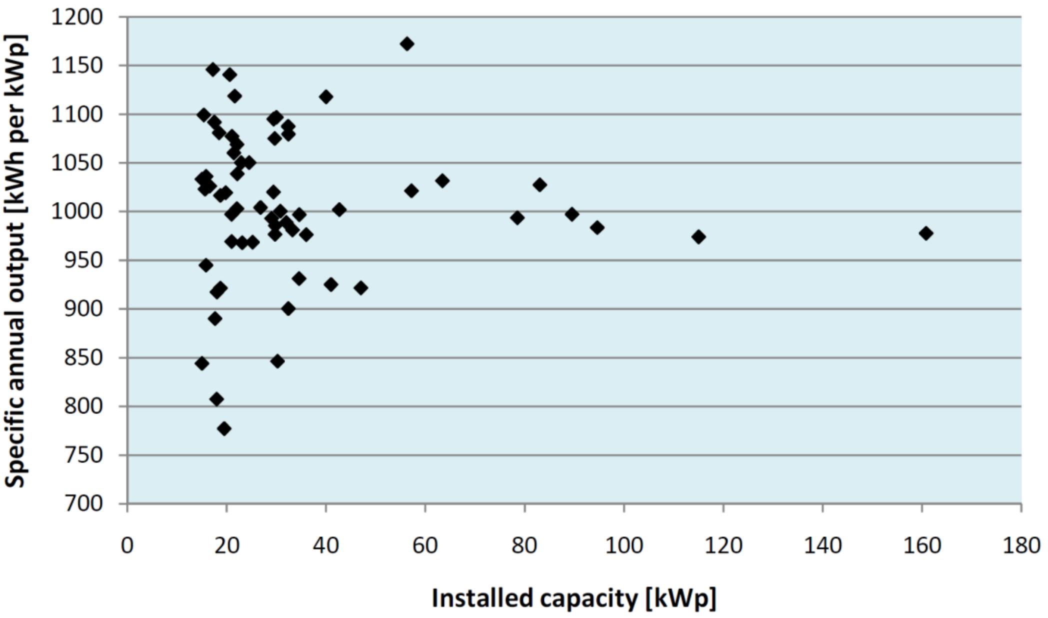

Fig. 13: Predicted specific annual output based on the measured output 2009 and an assumed module degradation of 0.5% per year (Source: compiled by the author).

The projected annual output shows a mean value of 1006kWh per kWp and a standard deviation of 79.9kWh per kWp. It suggests substantial differences among PV systems, which can be attributed to varying site qualities. A share of around 80% of empirically determined output values shown in Fig. 13 outvalues the legally assumed specific output of 950kWh per year. This provides evidence to the suggestion that output quantity was systematically underestimated in the context of the Swiss Energy Act.

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[60] The output values measured in 2009 were not adjusted to arithmetically averaged output conditions. See footnote 59 for a discussion of restrictions and uncertainties related to this approach.

6.1.3 Actual production costs in ‘Output 2009’ scenario

Actual production costs equal to total production costs (including operation and maintenance costs) divided by the estimated total output over lifespan. The first observation on actual costs shown in Fig. 14 concerns the pronounced variation around the mean value of CHF 0.67 per kWh. A standard deviation of CHF 0.09 per kWh reflects substantial variations in total costs and in specific output observed in Fig. 12 and Fig. 13.

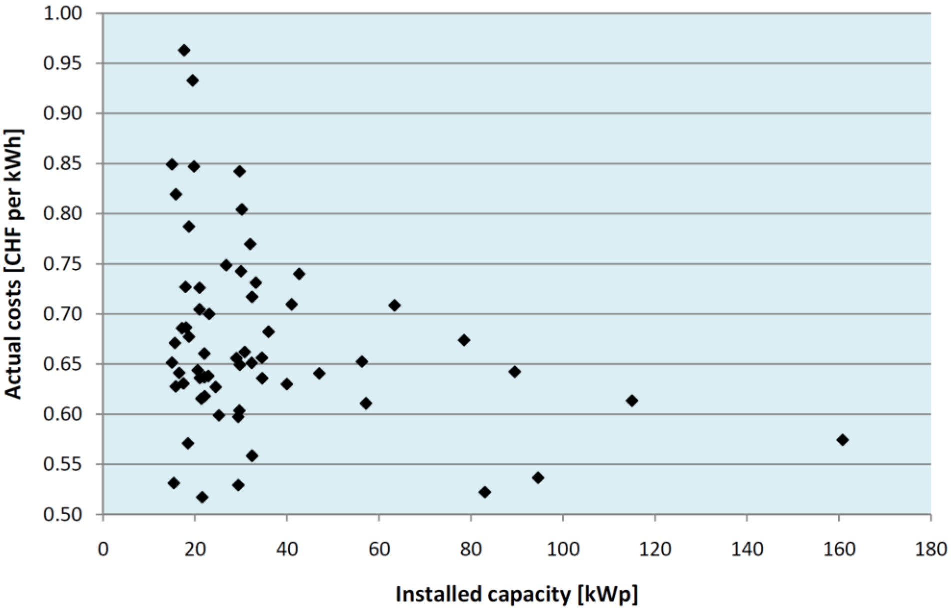

Fig. 14: Actual costs of PV power production in the ‘Output 2009’ – scenario (Source: compiled by the author).

Deduced from the distribution of observations shown in Fig. 14, there is evidence to suggest that economies of scale exist. It needs to be stated that this claim has a limited validity as the number of plants with an installed capacity >40kWp is small. The variance regarding actual costs appears to be much more distinctive for smaller PV plants. A high share of operators with an installed capacity <40kWp produces at costs below 65 cents per kWh, which points at the possible existence of market failures. It is not far to seek that the limited size of the Swiss PV market may partly explain the existence of market failures.

6.1.4 Actual production costs in ‘SFOE 950kWh’ scenario

In comparison with actual costs of ‘Output 2009’ scenario, actual production costs calculated by assuming a fix specific output of 950kWh are expectedly higher. The mean value of CHF 0.71 corresponds to a mean increase in costs of 6%. In contrast, the variance is slightly lower (standard deviation of CHF 0.08).

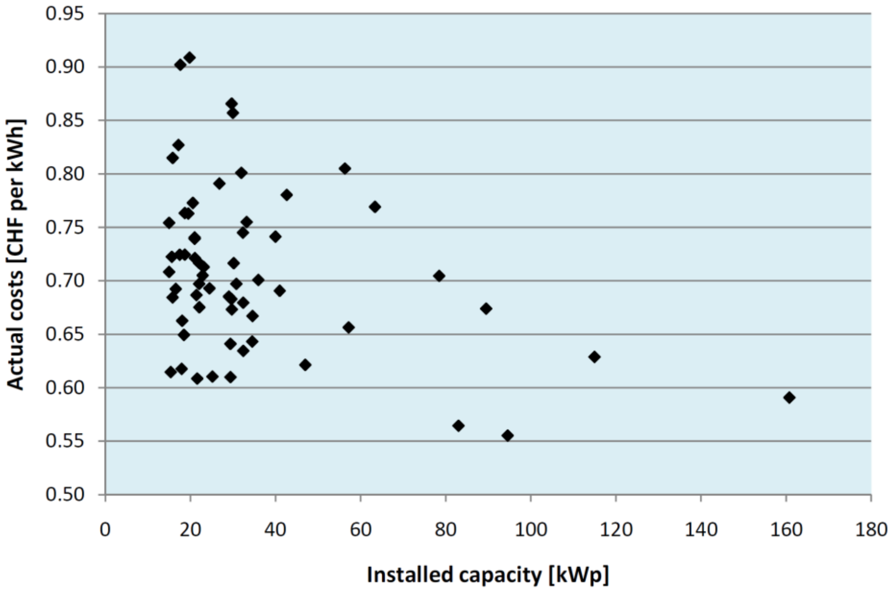

Fig. 15: Actual costs in PV power production in the 'SFOE 950kWh'-scenario (Source: compiled by the author).

As shown in Fig. 15, the pronounced variance for plants with an installed capacity <40kWp remains existent even if differences in output are disregarded. A more sophisticated discussion of operators with low actual costs will follow in the context of appearing resource rents.

6.1.5 Resource rents in 'Output 2009' scenario

The concept of resource rent is central to the investigation of cost-effectiveness. By subtracting actual production costs from feed-in remuneration, appearing resource rents of investigated PV plants can be deduced. These are hence economic profits beyond the normal rate of return of 5% which is included in feed-in tariffs. Resource rents may occur due to site-specific characteristics influencing output or costs. Thus, there has to be distinguished between the cost-effect and the output-effect, whereas both effects normally contribute to the appearance of a resource rent. Thereby, it has to be stated that variations in output or costs cannot implicitly be allocated to site-specific characteristics. Particularly variations in investment costs shown in subsection 6.1.1 need to be partly assigned to market failures rather than to site-specific characteristics. Under the assumptions of the 'Output 2009' scenario, a share of 62% of investors realizes an economic profit above the normal rate of return of 5% which included in the feed-in remuneration (see Fig. 16). The extent of appearing resource rents lies in the range of almost zero to around CHF 0.18 per kWh of produced electricity. On the other hand, a share of 38% of investors produces at costs above the level of feed-in remuneration resulting in losses up to CHF 0.25 per kWh of produced electricity. On average, the operators of investigated PV plants realize a resource rent of CHF 0.01 per kWh, which indicates that feed-in tariffs cover the actual costs quite precisely in the mean of the sample.

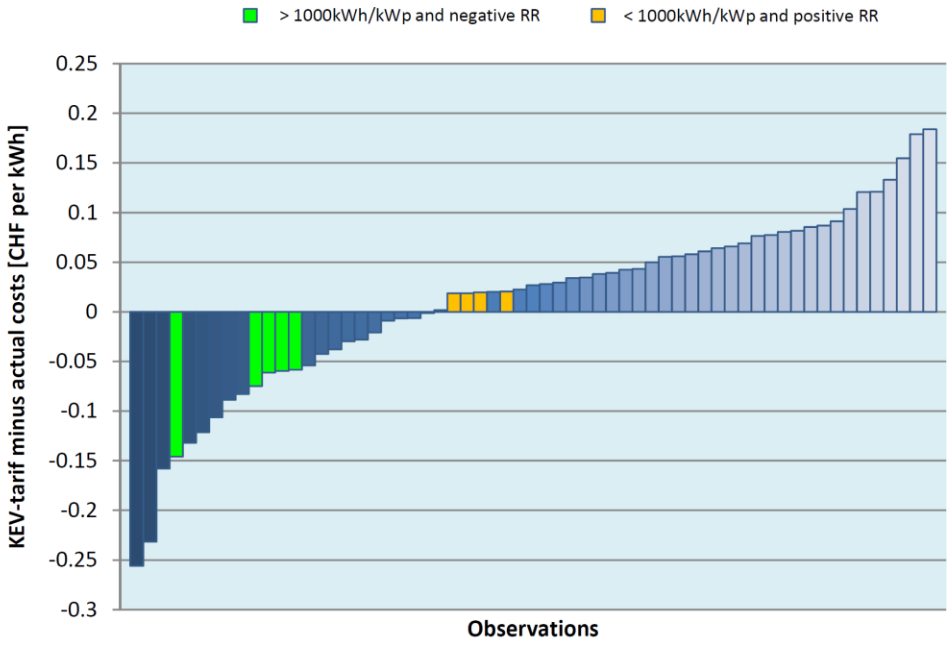

Fig. 16: Resource rents appearing among investigated PV plants based on the 'Output 2009' scenario assumptions with regard to the output effect (Source: compiled by the author).

As shown in Fig. 16, the share of operators with a substandard output value realizing a positive resource rent (highlighted in yellow colour) is pronouncedly low. The same is true for the share of operators with an output above average realizing a negative resource rent (green colour). This provides evidence to suggest that the output-effect on the appearance of resource rents is certainly considerable. Furthermore, a possible dependence of the magnitude of appearing resource rents on plant size was checked. A low correlation coefficient (Pearson's r = 0.076) suggests a negligible dependence.

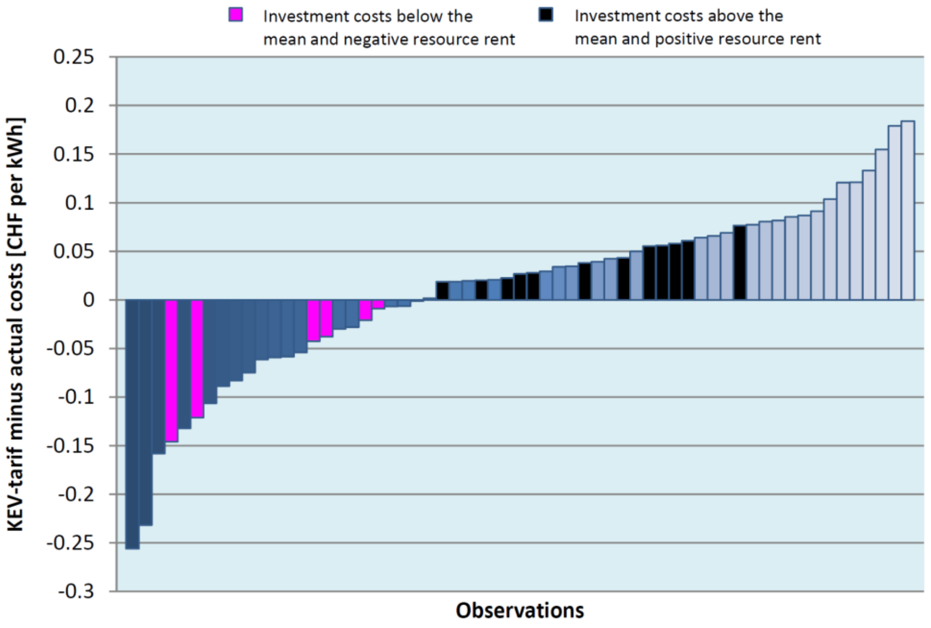

Fig. 17: Resource rents appearing among investigated PV plants based on the 'Output 2009' scenario assumptions with regard to the cost-effect (Source: compiled by the author).

Fig. 17 gives an indication of the cost-effect on the appearance of resource rents. A considerable share of operators with investment costs above average[61] realize a positive resource rent (black colour), while 6 operators with substandard investment costs realize a negative resource rent (purple colour). In comparison with results shown in Fig. 16, the output-effect appears to be significantly stronger than the cost-effect.

6.1.6 Resource rents in 'SFOE 950kWh' scenario

Substantial changes in results appear if calculations are based on the legally made output assumptions 'SFOE 950kWh'[62]. A share of over 60 % of investors produces at costs above the level of feed-in remuneration and realizes losses up to CHF 0.21 per kWh of produced output. Meanwhile, a remaining share of around 39% realizes a resource rent (see Fig. 18).

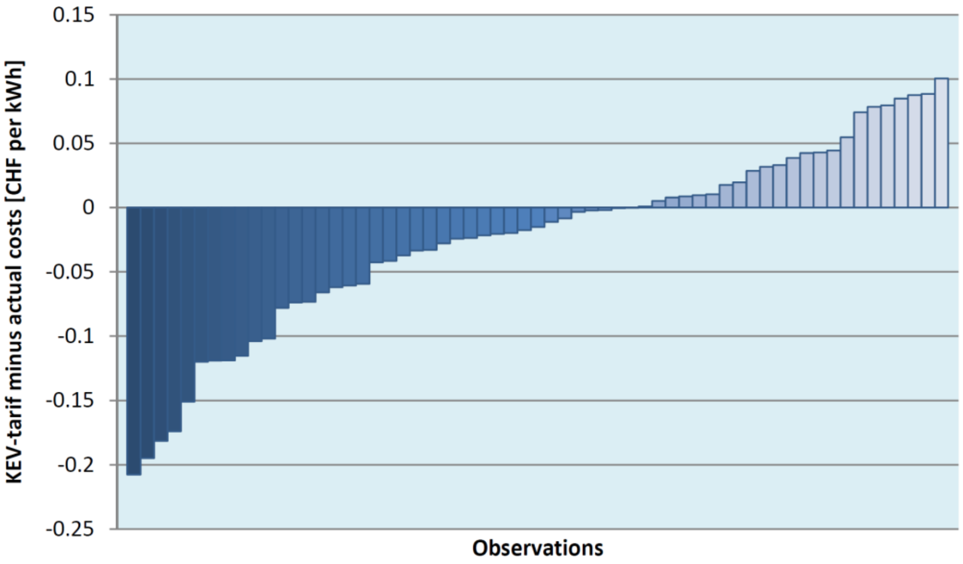

Fig. 18: Resource rents appearing within the investigated sample of PV plants based on the 'SFOE 950kWh' scenario assumptions (Source: compiled by the author).

6.1.7 Inefficiently employed public funds in 'Output 2009' scenario

On the basis of calculated resource rents, the total amount of inefficiently employed public means can be deduced. For this purpose, the resource rent of each investor is multiplied by its total annual output resulting in absolute amounts of inefficiently employed feed-in remuneration (see Fig. 19). If these amounts are totalized and interrelated to the total amount of financial support that was paid to the operators, it becomes obvious that 7% of total public funds are spent on resource rents and are thus inefficiently employed.

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[61] As specific investment costs depend on the size of the plant, they were normalized by dividing by the corresponding feed-in tariff.

[62] Specific annual output of 950kWh per kWp of installed capacity is assumed.

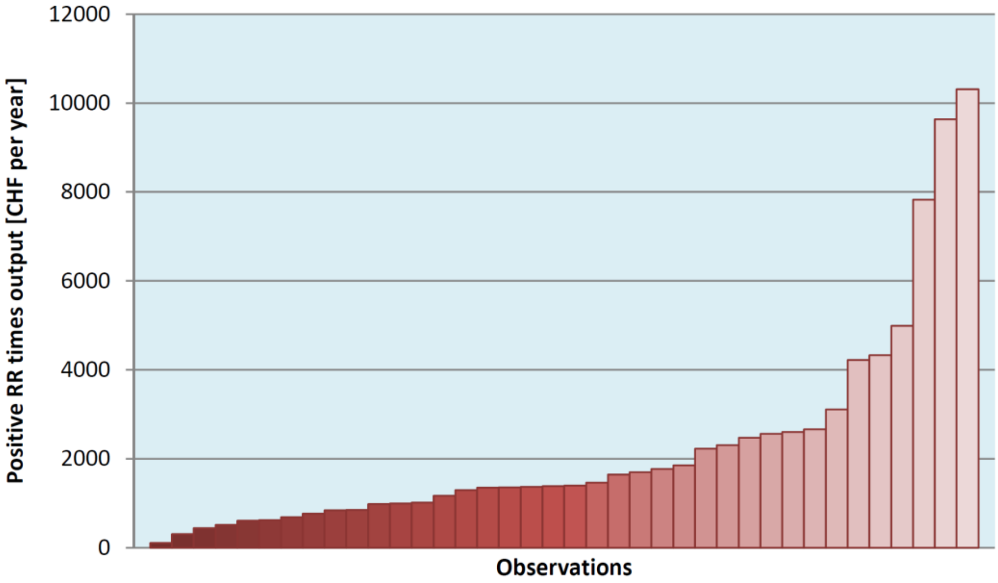

Fig. 19: Resource rents multiplied by the total annual output based on ‘Output 2009’ assumptions (Source: compiled by the author).

6.1.8 Sensitivity of actual costs to changing parameters

Due to the capital intensity of PV power production, the assumptions regarding interest on capital have strong implications for actual costs of PV electricity. Moreover, actual costs highly depend on the projected specific output.

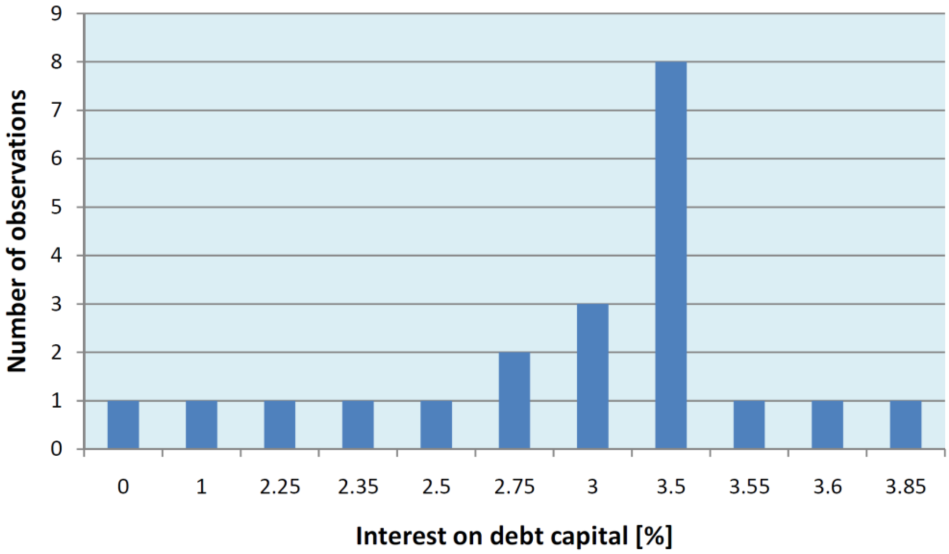

Fig. 20: Interest rates on debt capital of PV plant operators (Source: compiled by the author).

Therefore, knowledge about the sensitivity of actual costs[63] to changing interest rates and specific output levels is of relevance with respect to effectiveness measurements of promotion systems. Within the context of the Swiss supporting system KEV, an interest rate of 5% on debt and equity capital is fixed. Meanwhile the interest rate of 5% on equity can be justified with a risk surcharge, the interest rate on debt capital is supposed to cover actual capital costs of investors. Within the context of this study, a number of 21 investors declared the interest rates on debt capital (see Fig. 21). A mean interest rate on debt capital of 2.93% with a modal score of 3.5% can be observed. Based on this information, it can be stated that current interest rate on debt capital assumed within the KEV is around 1.5% above the actual interest rates. Considering the calculated sensitivity in Fig. 21, lowering the interest rate on debt capital by 1.5% would lead to a decrease of actual production costs by around 4%, 6.5% or 9.1%[64] respectively. These figures point to a further source of cost-ineffectiveness inherent in the KEV caused by deviating interest rates from assumed values.

As discussed in subsection 6.1.2, there is a deviation of 56kWh per kWp between the projected specific output (based on the output 2009) and the legally defined output of 950kWh per kWp. Considering the sensitivity of actual costs to output quantity, a positive deviation of 56kWh from assumed 950kWh leads to a decrease in actual costs of 5.8% (see Fig. 21).

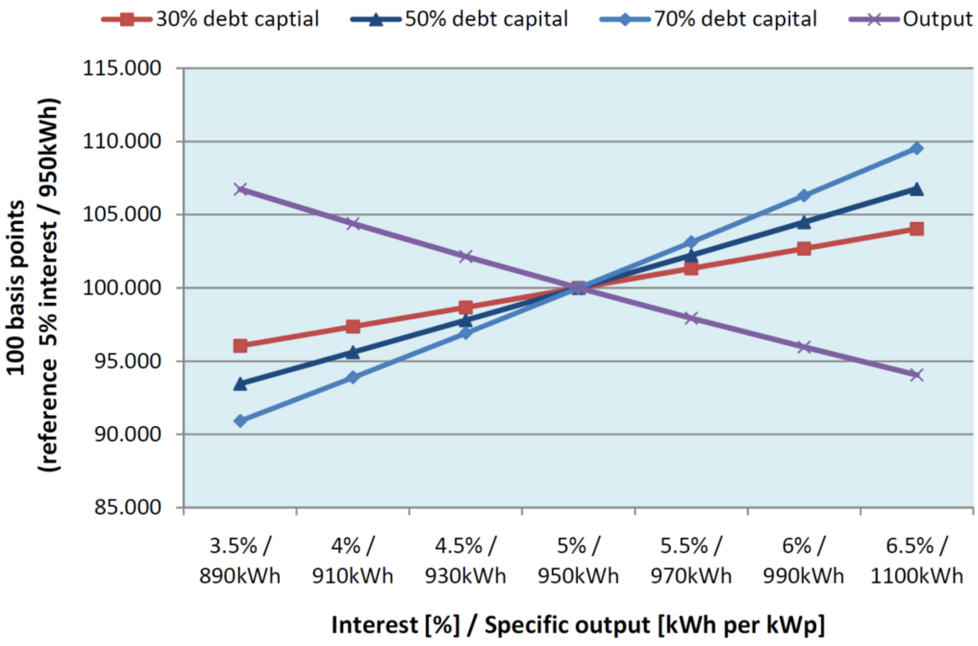

Fig. 21: Sensitivity of actual production costs to changing interest rates and specific output (Source: compiled by the author).

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[63] See calculations in subsection 6.1.3 and 6.1.4.

[64] Depending on the assumed share of debt capital of 30%, 50% or 70%, respectively.

7 Interpretation of results

7.1 Verification of hypotheses

7.1.1 Hypothesis A: High variation in actual costs

On the basis of presented results it can be stated that the variation among PV plants concerning total investment costs and projected output is distinctly high. On average, total investment costs deviate by 12.2% from mean value while the specific output deviates by 7.9% from mean value resulting in actual costs with a standard deviation of 13.5%. Therefore, hypothesis A formulated in subsection 5.4 can be verified.

Regarding variation in total investment costs, no significant effects of variables with geographical interdependencies could be derived from collected data. Accordingly, there is no empirical evidence provided which would suggest a gradation of feed-in tariffs with respect to cost factors. The design of the present study is not geared to quantify the effect of factors determining output and thereby to explain the variance in output. However, presented output results support the conclusion that actual output rates lie around 5% above the legally assumed specific output of 950kWh. This can be declared as a relevant source of appearing cost-ineffectiveness in the Swiss supporting system KEV.

7.1.2 Hypothesis B: Cost-ineffectiveness in terms of resource rents

Attributable to the high variation in actual production costs among operators, a high share of around 60%[65] of investors produces at costs below feed-in tariffs realizing positive resource rents up to CHF 0.18 per kWh. This circumstance can partly be explained by a general underestimation of specific output rates when calculating legally defined feed-in tariffs. Within the investigated sample, the ratio of public funds spent on resource rents accounts for 7% of total public support. Consequently, hypothesis B can be verified.

Principally, the appearance of resource rents can be attributed either to preferable cost-conditions (cost-effect) or to preferable output conditions (output-effect). In reality, both effects turn out to be involved when the root causes are determined. The output effect appears to be more powerful in the present sample, since almost no operator realizes a positive resource rent with a substandard output below 1000kWh/kWp. In contrast, a substantial share of operators with investment costs above the average realizes a positive resource rent. Thereby, it has to be stated that the cost-

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[65] Assuming specific output rates of ‘Output 2009’ scenario.

effect cannot implicitly be allocated to site-specific characteristics. Rather, appearing market failures lead to high variances in specific investment costs.

In order to reduce the appearance of resource rents, a system change towards individual feed-in remuneration for each investor tailored on its actual production costs would be mandatory. The option of a bidding procedure, which is favored by economists, implicates the disadvantage of possible implementation delays (see subsection 3.5.5). Furthermore, the alternative solution of individually defined feed-in tariffs based on actual investment costs and actual output would cause high administrative burdens and simultaneously eliminate the incentive to produce at lowest costs. In default of ideal solutions, a simple approach is suggested here in order to reduce the potential of appearing resource rents within the Swiss remuneration system KEV. On the one hand, a raise of the legally assumed specific output from a current level of 950kWh to a more ambitious level would gear the system to the most favorable locations by lowering feed-in tariffs. On the other hand, PV operators producing at output levels above the legally projected quantity should only be remunerated for a fractional amount of supplementary output. This can be justified by the fact that feed-in tariffs are calculated on the basis of an assumed output of 950kWh/kWp. Thus, actual production costs of investors are covered if the amount of 950kWh/kWp is remunerated. A fractional amount of supplementary output should still be remunerated in order to sustain the incentive to maximize the output. Altogether, the potential of appearing resource rents would be substantially reduced.

7.1.3 Further results: System flexibility with regard to changing framework conditions

Apart from the investigation of hypotheses A and B, the issue of interest rates on debt capital is briefly discussed as it is of potential relevance for cost-effectiveness of promotion systems. As discussed in section 3.6.3, the calculation of feed-in tariffs in the context of the Swiss promotion scheme KEV is based on a normal rate of return of 5% on equity and debt capital. If interest rates on debt capital on financial markets are lower than the assumed 5%, plant operators realize an unjustified economic profit at the expense of promotion systems’ cost-effectiveness. Currently, empirically determined interest rates paid by the operators deviate by around 1.5% from the assumed 5% (see subsection 6.1.8 and Fig. 21). In order to minimize such economic profits, an ongoing adaptation of feed-in tariffs to mean interest rate levels is mandatory and moreover designated in the Swiss Energy Ordinance[66]. As a consequence, feed-in tariffs are to be ensured within a fluctuation band.

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[66] See EnV, Section 2, Art. 3e.

7.2 Cost-ineffectiveness from a GHG mitigation perspective

This subsection ranges the results of the present study in the context of GHG mitigation effect of RES promotion. With regard to discussed arguments in subsection 0, it is basically reasonable from a GHG mitigation perspective to promote photovoltaic power production. The appearance of cost-ineffectiveness obviously lowers the effectiveness of an RET promotion system regarding the achievement of its GHG mitigation targets. The GHG mitigation effect decreases proportionally to the increase in cost-ineffectiveness.

Apart from cost-effectiveness of a policy instrument, the preferential promotion of output-efficient producers is of certain relevance from a GHG perspective. A share of more than 97% of GHG emissions caused by PV power production is related to production of materials, installation and disposal or recycling of materials. Meanwhile, operation and maintenance of PV plants only account for around 2% of GHG emissions (Kaltschmitt et al. 2006a). As a consequence, GHG intensity of PV produced electricity is primarily determined by the total amount of produced electricity per unit of installed capacity. PV systems installed at unfavorable locations produce thus electricity with a higher CO_2 intensity. This can be illustrated by the spread of CO_2-intensities among power plants of the investigated sample: while the operator with highest specific output produces at a CO_2-intensity of 72.9g CO_2-eq. per kWh, the operator of the plant with lowest specific output produces at a level of 110g CO_2-eq. per kWh[67]. Therefore, the promotion of PV plants at more favorable locations leads to a decrease in CO_2-intensity of produced electricity.

A second aspect has to be considered with regard to CO_2-intensity of PV produced power. Life-cycle analyses provide empirical evidence for a decreasing CO_2-intensity with increasing scale of installed capacity. From an environmental point of view, this can be used as an argument to preferentially promote large plants.

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[67] These calculations are based on the assumption of a perfect proportionality between the increase of output and the decrease of CO_2-intensity. Furthermore, a baseline value of 90g CO_2-eq. per kWh according to Kaltschmitt et al. (2006a) is assumed.

7.3 Adaptation propositions for the supporting system KEV

The results of the present study may be considered whilst taking into account the limitations. These are notably the small number of observations and a scarce heterogeneity among observations regarding their costs. Nevertheless, a range of three adaptation propositions for the Swiss RET promotion system KEV are formulated on the basis of empirical evidence provided in the context of this study. The results of the present study provide evidence to suggest that the remuneration of PV produced electricity should be differentiated more distinctly taking into account site-specific characteristics. This can either be realized on by considering individual conditions of operators or by calculating feed-in remuneration with regard to an extended number of criteria, e.g. more types of plants or regional differentiations. The following adaptation propositions are targeted to increase cost-effectiveness of the promotion system in the field of photovoltaic power production.

1. **Increase of legally projected annual specific output:** More than 50% of investigated power plants have a projected annual output of >1000kWh per kWp over a lifespan of 25 years. Calculating feed-in tariffs based on a more ambitious output level above the current level of 950kWh per kWp would decrease the potential of appearing resource rents.

2. **Restricting remuneration of surplus outputs:** PV operators with a specific output >950kWh per kWp should only be compensated for a fractional amount of the output exceeding 950kWh. Thereby, the potential of appearing resource rents was substantially reduced while the incentive to maximize the output was preserved.

3. **Adopting a flexibility mechanism to consider changing interest rates:** Regulatory adjustments of interest rate levels on debt capital to actual circumstances on financial markets avoid additional cost-ineffectiveness. As a consequence, feed-in tariffs were guaranteed within a fluctuation band.

Altogether, any measures which increase cost-effectiveness of the promotion system and lower mean actual costs will lead to an enhanced acceptance of PV power production in politics and society. This accelerates technology development which finally belongs to the main targets of RET promotion.

8 Conclusions and outlook

Among renewable energies hydro power (up to 10MWp), photovoltaic energy, wind power, geothermal power and biomass energy, most technologies have not yet reached market maturity. In order to ensure technological progress resulting in cost competitive RETs, public support is inevitable for renewable energy technologies. Notably electricity from photovoltaic power production is far from being cost-competitive. There is strong scientific evidence for the utility of policy intervention moving the market towards a socially more efficient equilibrium. RET promotion can contribute to the removal of market failures, namely to the internalization of external environmental costs and external benefits of technological development. In the long term, it can be a measure to reach GHG emission reduction targets of a country and to ensure a secure electricity supply. Apart from that, positive side-effects such as enhanced employment effects appear.

The Swiss legislator adopted a cost-covering feed-in remuneration system (KEV) in 2007 aimed at a range of targets. While the system is characterized by a simple management and low transaction costs, it implicates the possible appearance of cost-ineffectiveness. Since feed-in tariffs are fixed over plants' lifespan and only depend on applied technology, date of entry into service and installed capacity, site-specific variations influencing total costs or specific output stay unattended. Thereby, investors can realize economic profits above the normal rate of return of 5% included in feed-in tariffs. These so called 'resource rents' can appear for instance if operators benefit from favorable site-characteristics. Resource rents may be an indication for cost-ineffectiveness of a promotion system. As the KEV does not include a mechanism preventing the appearance of resource rents, the legal obligation of 'cost-covering' feed-in tariffs may not be fulfilled.

Based on a sample of 65 roof-mounted PV power plants recorded in the KEV, the cost structure of PV systems was empirically analyzed in the context of this study. As a principal issue, actual costs of PV power production were derived from descriptive statistics and compared with feed-in remuneration provided by the Swiss promotion system KEV. The following core insights can be deduced from the results:

- The variances among operators regarding investment costs and specific output are considerable, whereby site-specific factors and the existence of market failures belong to the possible causes.
- A significant share of PV plant operators is expected to realize an economic profit (resource rent) above the normal rate of return over the entire lifespan of the plant. Cost-ineffectiveness in the range of around 7% of invested public funds can be related to appearing resource rents.
- This can firstly be explained by substantial variances regarding specific costs and output resulting in actual production costs with a standard deviation of 13.5% from mean value. Se-

condly, mean actual output appears to be around 5% above the legally assumed level of 950kWh per kWp.

The present study is faced with a range of framework conditions limiting the force of expression of the results. For instance, the number of observations is small and its distribution regarding geographical parameters or plant size is certainly suboptimal. Moreover, heterogeneity among observations could partly not be captured due to lack of empirical values, which constrains empirical analyses. For instance, operation and maintenance costs are related to high uncertainties containing hence a cost-inefficiency potential for investors. Since operation and maintenance costs are widely unknown, they could not be captured.

However, two recommendations for promotion system adaptations can be formulated based on the derived insights: Firstly, the legally assumed average specific output of 950kWh should be increased to a more ambitious level. Thereby, the pressure on investors to choose output-efficient locations would be enhanced. Simultaneously, the CO_2-intensity of produced electricity was lowered. Secondly, operators producing at output levels above the legally defined quantity should only be remunerated for a fractional amount of the additional output. As a result, the incentive to produce output-efficiently would remain existent, while a substantial share of potential resource rents was removed.

The attainment of insights in the context of the present study has some implications in respect of further investigations in the field of PV produced electricity. In general, the enhanced identification of heterogeneity among plant operators’ costs would widen the scope for empirical analyses. For instance, empirical values of operation and maintenance costs will probably be available in 10 to 15 years reducing the uncertainties of cost estimations substantially. Furthermore, an investigation of factors determining output and their dependencies on geographical or environmental parameters could provide evidence for the need of regionally graded feed-in tariffs. It would certainly be insightful to estimate average costs of PV power production by running an econometric model[68]. By including all relevant output and cost variables, the estimated average cost function could for instance be used to project actual production costs of an operator considering relevant determinants. This could be a possible way to define individual feed-in remunerations under allowance of site-specific characteristics.

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[68] In the context of the present empirical analyses, an econometric model was run in order to get a feel for the potential and possible difficulties appearing with regard to cost modeling. On the one hand, it became obvious that the complexity of determining output of PV power production is considerably high as a wide range of relevant variables with partly contrary effects on output exists. On the other hand, the heterogeneity regarding relevant costs factors may hardly be captured, e.g. as a consequence of the absence of empirical values. Thus, the estimation of a reliable average cost function would certainly be connected to high difficulties.

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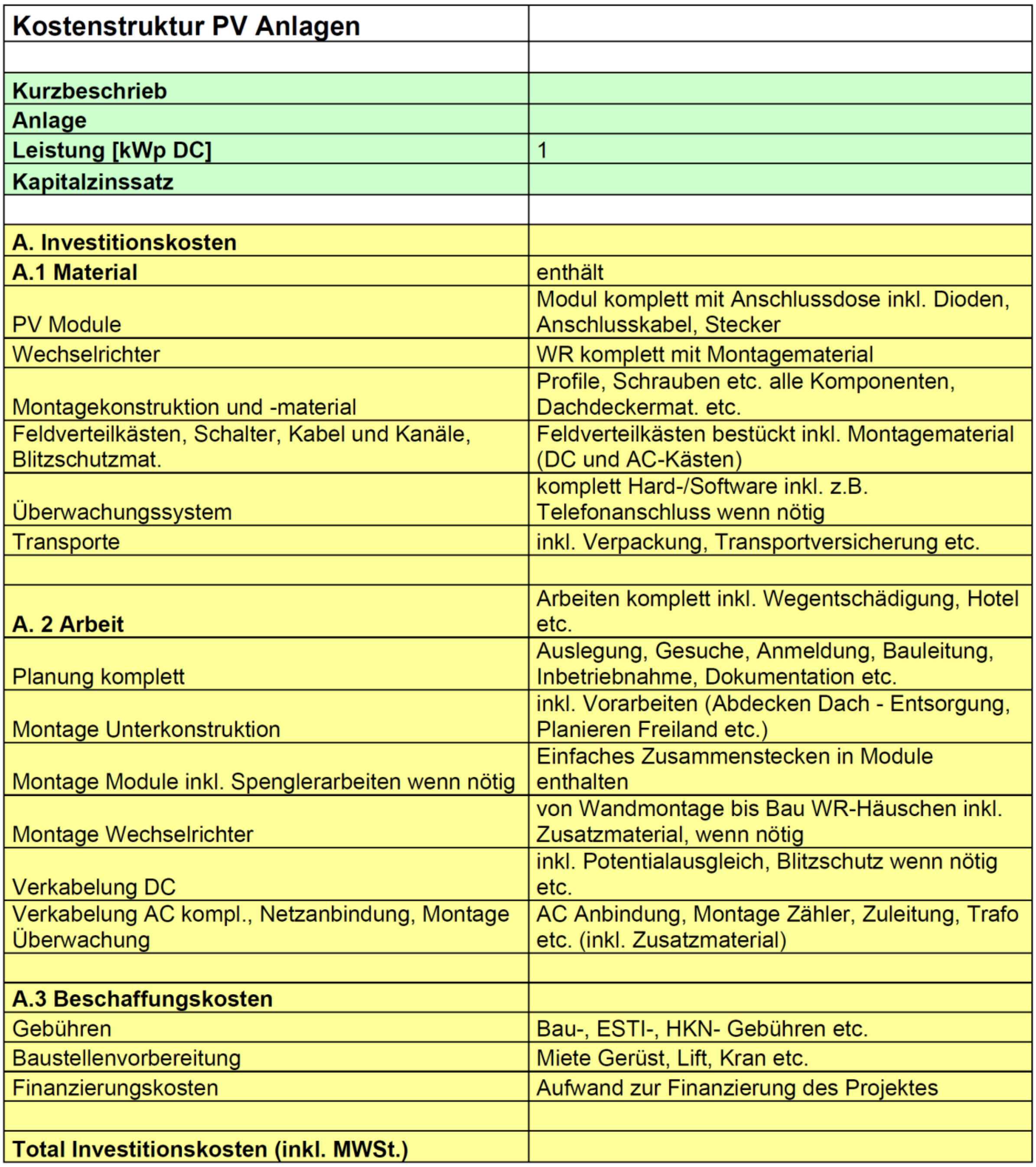
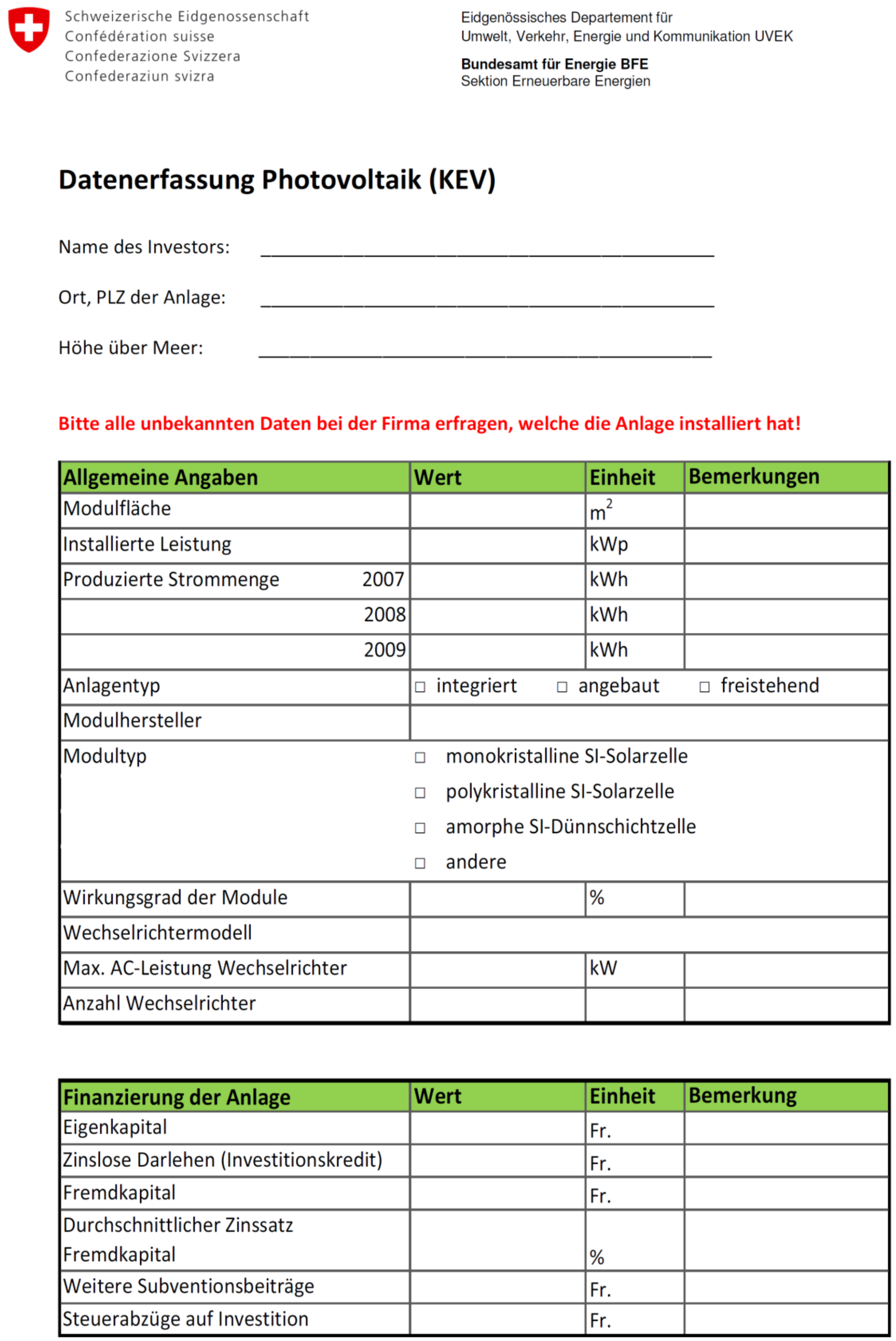
Annex I: Cost factors of PV power production according to the Swiss Energy Ordinance, Annex 1.2



Kostenstruktur PV Anlagen	
Kurzbeschrieb	
Anlage	
Leistung [kWp DC]	1
Kapitalzinssatz	
A. Investitionskosten	
A.1 Material	enthält
PV Module	Modul komplett mit Anschlussdose inkl. Dioden, Anschlusskabel, Stecker
Wechselrichter	WR komplett mit Montagematerial
Montagekonstruktion und -material	Profile, Schrauben etc. alle Komponenten, Dachdeckermat. etc.
Feldverteilkästen, Schalter, Kabel und Kanäle, Blitzschutzmat.	Feldverteilkästen bestückt inkl. Montagematerial (DC und AC-Kästen)
Überwachungssystem	komplett Hard-/Software inkl. z.B. Telefonanschluss wenn nötig
Transporte	inkl. Verpackung, Transportversicherung etc.
A. 2 Arbeit	Arbeiten komplett inkl. Wegentschädigung, Hotel etc.
Planung komplett	Auslegung, Gesuche, Anmeldung, Bauleitung, Inbetriebnahme, Dokumentation etc.
Montage Unterkonstruktion	inkl. Vorarbeiten (Abdecken Dach - Entsorgung, Planieren Freiland etc.)
Montage Module inkl. Spenglerarbeiten wenn nötig	Einfaches Zusammenstecken in Module enthalten
Montage Wechselrichter	von Wandmontage bis Bau WR-Häuschen inkl. Zusatzmaterial, wenn nötig
Verkabelung DC	inkl. Potentialausgleich, Blitzschutz wenn nötig etc.
Verkabelung AC kompl., Netzanbindung, Montage Überwachung	AC Anbindung, Montage Zähler, Zuleitung, Trafo etc. (inkl. Zusatzmaterial)
A.3 Beschaffungskosten	
Gebühren	Bau-, ESTI-, HKN- Gebühren etc.
Baustellenvorbereitung	Miete Gerüst, Lift, Kran etc.
Finanzierungskosten	Aufwand zur Finanzierung des Projektes
Total Investitionskosten (inkl. MWSt.)	

B. Betriebskosten	
Miete Fläche	Dachfläche, Land, usw.
Miete Zähler	Separater elektrischer Zähler
Rückstellungen	für Erneuerungen, z.B. Wechselrichter
Verwaltungskosten	Interne Verwaltung, Versicherung, Steuern
Unterhaltskosten	Regelmässige Unterhaltskosten
Total Betriebskosten (exkl. MWSt.)	
MWSt.	
Total Betriebskosten (inkl. MWSt.)	

Annex II: Schedule for data collection used for this study



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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE
Sektion Erneuerbare Energien

Datenerfassung Photovoltaik (KEV)

Name des Investors: ______________________________

Ort, PLZ der Anlage: ______________________________

Höhe über Meer: ______________________________

Bitte alle unbekannten Daten bei der Firma erfragen, welche die Anlage installiert hat!

Allgemeine Angaben	Wert	Einheit	Bemerkungen
Modulfläche		m^2	
Installierte Leistung		kWp	
Produzierte Strommenge 2007		kWh	
2008		kWh	
2009		kWh	
Anlagentyp	☐ integriert ☐ angebaut ☐ freistehend		
Modulhersteller			
Modultyp	☐ monokristalline SI-Solarzelle ☐ polykristalline SI-Solarzelle ☐ amorphe SI-Dünnschichtzelle ☐ andere		
Wirkungsgrad der Module		%	
Wechselrichtermodell			
Max. AC-Leistung Wechselrichter		kW	
Anzahl Wechselrichter			

Finanzierung der Anlage	Wert	Einheit	Bemerkung
Eigenkapital		Fr.	
Zinslose Darlehen (Investitionskredit)		Fr.	
Fremdkapital		Fr.	
Durchschnittlicher Zinssatz Fremdkapital		%	
Weitere Subventionsbeiträge		Fr.	
Steuerabzüge auf Investition		Fr.	

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Bundesamt für Energie BFE
Sektion Erneuerbare Energien

Kosten	Wert	Einheit	Bemerkung
Planungskosten der Anlage		Fr.	
Solarmodule		Fr.	
Materialkosten (Befestigungssystem Module)		Fr.	
Materialkosten Installation (Radox-Kabel, Stecker, Litzen, Schutzrohre)		Fr.	
Kosten Montage (Fremdleistung)		Fr.	
Eigenleistung Montage		Stunden	
Arbeit und Material für Netzanschluss (Sicherungs- und Zählerkasten, Leitung vom Wechselrichter zum Zählerkasten)		Fr.	
Wechselrichter (Miete oder Kauf)		Fr.	
Netzverstärkungskosten		Fr.	
Einspeisezähler (Miete) und Netzgebühren		Fr./Jahr	
Elementarschadensversicherung (meist in Gebäudeversicherung)		Fr./Jahr	
Haftpflichtversicherung		Fr./Jahr	
Betriebsausfallversicherung		Fr./Jahr	
Betriebs- / Unterhaltskosten (Rückstellung)		Fr./Jahr	

Weitere Rahmenbedingungen	Wert	Bemerkung
Neigungswinkel des Daches		Grad
Geogr. Ausrichtung der Anlage		Abweichung von Süden, in Grad
Schattenwurf (z.B. Vegetation)		kein / wenig / erheblich
Horizonthöhe / -verschattung		tief / mittel / hoch
Häufigkeit Wartung/Funktionskontrolle		regelmässig / selten / nie
Investitionsgrund / -motivation		ökonomisch / ideologisch
Wirtschaftlichkeitsrechnung		ja / nein
Weitere erneuerbare Energien?		
Distanz der Anlage zum Siedlungsraum		innerhalb / nahe / weit entf.
Unterlüftung der Anlage		gut / mässig / schlecht
Bauaufwand (Gerüstnotwendigkeit)		ja / nein
Art des Investors		Privatperson / Firma

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Erklärung

gemäss Art. 28 Abs. 2 RSL 05

Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Abs. 1 Buchstabe o des Gesetzes vom 5. September 1996 über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, 08.10.2010