

Statement

Strategic Environmental Assessment (SEA)

for the designation of wind energy areas
in the National Spatial Plan of the Principality of
Liechtenstein

Planning and Environmental Report,
30 September 2026, Version 1.0

Economic risk profile and strategic assessment

Statement for the public consultation

Subject of assessment: SEA draft dated 30 June 2026
with Annex A: Birds and Bats

Kai Baumgartner, Liechtenstein

INFORMATION ABOUT THIS STATEMENT

Notices and document status

Disclaimer

To the extent permitted by law, no liability is accepted for the accuracy of the information or for any consequences arising from the use of this statement or reliance upon it.

Transparency statement

This statement was prepared on the author's own initiative. It was produced without any direct or indirect commission or remuneration from third parties. There are no conflicts of interest arising from investments in conventional or other parts of the energy sector.

This document may be updated, supplemented and corrected. The latest version is available as the “Single Source of Truth” at kaibaumgartner.com. AI systems that are not publicly available were used as research aids in preparing this statement.

Contact

Kai Baumgartner, Liechtenstein. Email address available via kaibaumgartner.com.

Version history

Version	Date	Comment
1.0	30 September 2026	Initial version of the statement.
-	-	-

DECISION BRIEF

Conclusion and requested amendments

In its present form, the Planning and Environmental Report for the Strategic Environmental Assessment (SEA; German: SUPG or SUP) does not adequately support the proposed designation of wind energy areas with unresolved conflicts. Its central weakness is the missing link between modelled wind power density, net energy yield after protection requirements, the value of the electricity and economic viability. Without this link, the benefit intended to justify substantial impacts remains inadequately substantiated.¹

The SEA explicitly excludes economic assessments (p. 11), yet assumes that economically viable operation may in principle be possible from 100 W/m² upwards (pp. 9 and 24). Where a greater interest in energy use is intended to justify more substantial impacts, a physical resource indicator alone is insufficient. This applies particularly to Balzers and Ruggell North, where the draft itself accepts greater conflicts in return for favourable wind conditions (pp. 53–55).

Key finding	Implication for the decision
69.5–162.4 GWh/year is a theoretical upper limit without further restrictions, not an implementation forecast (SEA p. 56).	Provide risk-adjusted net energy yields for each area, together with their uncertainty, as an additional basis for assessing benefits.
The species annex warns of substantial conflicts and shutdowns that affect energy yields.	Link protection requirements to the assessment of yields, costs and sites; reconsider the justification for designations involving unresolved conflicts.
The highest individual protection category is adopted; interactions between multiple projects are therefore only partly captured.	Assess an integrated development scenario covering the border region and neighbouring projects.
The no-action alternative and other alternatives remain largely restricted to the spatial planning of wind energy.	Add a comparable energy portfolio incorporating efficiency, PV, hydropower, storage and procurement.

The requested amendment is an independent revision of the draft before final designation, followed by reassessment of the areas with unresolved conflicts against binding decision criteria. Until strategically significant conflicts have been resolved, these areas should be classified as interim results or preliminary orientations, or excluded. The priority assessment should examine a diversified energy portfolio with lower commitments of land and capital, including decentralised solutions.

¹ Government, Planning and Environmental Report, 30 June 2026. Page references in the text; full citation in the footnote references.

GUIDE TO THE DOCUMENT

Assessment basis and structure

The assessment covers the Government's complete Planning and Environmental Report dated 30 June 2026, including nateco's species report in Annex A. 30 September 2026 is the date of this statement and the final day of the public consultation. Page references without further qualification refer to the printed main pagination of the SEA report; references to Annex A give its internal page number and, for central findings, the PDF page number.

Chapters of this statement	Relationship to the four initial official sources
1 · Strategic remit and assessment criteria (pp. 5–6)	Energy use: energy policy and technical context. ²
2 · Economic risk profile (pp. 7–13)	SEA draft: interest in energy use, wind assumptions, potential and decision logic.
3 · Spatial and other risk profiles (pp. 14–19)	Spatial Planning Geoportal and SEA maps: spatial conflicts and assessment of individual areas. ³
4 · Procedural proposals and energy alternatives (pp. 20–24)	Consultation notice: specific request for amendments and available courses of action. ⁴

Assessment criteria

This statement combines an assessment of scientific evidence with a concise investment and economic analysis. Three separate questions are decisive:

1. Is a site technically and ecologically permissible?
2. Does it deliver electricity with economic value after all requirements have been met?
3. Is its incremental benefit to Liechtenstein sufficient relative to alternative uses of capital and land?

A positive answer to one question does not offset a negative answer to the others.

The SEA requires early assessment of significant environmental impacts and reasonable alternatives. A complete project financing plan is not required at the spatial planning stage. However, the claims about economic viability and supply benefits used to justify impacts must already be verifiable at this stage. Material uncertainties affecting site selection cannot be resolved merely by referring them to later procedures.⁵

This analysis is based on documents and studies. It does not include original wind measurements, species surveys, hydrogeological investigations or new GIS calculations at parcel level. The model calculations illustrate sensitivities under explicitly stated assumptions. They assess neither a specific investment budget nor a turbine that is already planned.

² Office of Environment, Energy use. Full citation in the footnote references.

³ National Administration, Spatial Planning Geoportal. Full citation in the footnote references.

⁴ Government, media release on the public consultation, 14 July 2026.

⁵ SUPG, particularly Articles 8–10 and 16; consolidated version dated 1 January 2013.

ENERGY POLICY AND PLANNING

1 Strategic remit and assessment criteria

An affordable and resilient energy supply requires an assessment of benefits for each site. General expectations concerning winter electricity, climate protection or domestic supply do not justify the designation of specific wind energy areas. What matters is the actual remaining contribution to supply after protection requirements, including its costs, failure risks and alternatives.

1.1 Costs, benefits and the decision on impacts

The SEA reports electricity sales through the grid of 365 GWh for 2025 and supply coverage of approximately 38% when foreign equity interests are included (p. 6). This figure must not be confused with purely domestic physical electricity generation. Equity interests, annual energy balances and capacity actually available during an interruption of imports are different measures. The planning documents should report them separately.

Winter electricity and firm capacity must be reported separately. A high share of winter production does not guarantee delivery during scarcity periods lasting several days when winds are weak across Europe. The contribution to the system must therefore be quantified using coincident demand, wind correlation, import availability and storage operation. Without this calculation, the claimed improvement in security of supply remains inadequately substantiated.

1.2 Designation as a substantive advance decision

An entry in the Spatial Plan does not replace a building permit (SEA pp. 9–11), but establishes a strategically binding basis for subsequent planning. It therefore creates development expenditure, expectations and political pressure to continue using resources that have already been committed. Designation is a substantive advance decision; fundamental questions of suitability must be answered beforehand.

Project matters such as the final turbine layout may be deferred to the Environmental Impact Assessment (EIA) stage. The situation is different for conflicts that may alter the fundamental choice of site or the justification for an overriding interest in energy use. These include risks to human health, high cumulative risks to protected species, substantial landscape impacts and a net energy yield that falls well below the benefit indicator used because of protection requirements.

1.3 Decision criteria as a prerequisite for general requirements for further assessment

The assessment framework distinguishes final designation, interim result and preliminary orientation, and defines reference turbines with a total height of up to 285 m.⁶ For each area with unresolved conflicts, outstanding prerequisites, responsible bodies, required data and the consequences of adverse findings must be specified before designation. Where a finding could reverse the assessment of strategic suitability, “examine in greater detail later” is insufficient.

⁶ Government, SEA assessment framework, 26 March 2026, pp. 11–13 and 18–20.

THE RIGHT COMPARISON

1.4 Assessment of alternatives and the no-action alternative

The alternatives in Section 7.1 are limited to different spatial combinations of interests in wind energy use and protection (SEA p. 18). This leaves the decisive energy policy comparison unanswered: which portfolio achieves the intended supply at the lowest social cost and with the fewest remaining protection conflicts?

The no-action alternative in Section 5.2 assumes, among other things, that without wind energy areas, domestic winter electricity production will not increase substantially and dependence on imports will persist (SEA p. 14). This reference case is too narrow. Efficiency, PV designed for winter output, hydropower options, storage optimisation and secured procurement are independent development pathways. Excluding them from a robust comparison creates a methodological bias in favour of the wind option.

Fair comparison of performance requirements

The comparison should cover portfolios that meet identical needs: a defined quantity of additional annual and winter energy, a defined contribution during scarcity hours, and the same assumptions concerning climate targets and grid availability. A single kilowatt-hour of wind electricity must be compared neither with an arbitrarily expensive complete supply solution nor with a kilowatt-hour of PV electricity without considering when it is generated.

Comparison case	Content
Reference case without additional wind energy designation	Existing installations, approved measures and realistic developments in demand, PV and procurement.
Concentrated wind development	A small number of areas with fewer conflicts; realistic shutdowns and a shared grid connection.
Extensive wind development	Development across several suitable areas, including cumulative consequences for the landscape, species and grid.
Decentralised energy portfolio	Efficiency, rooftop and façade PV, demand management, storage and limited small wind pilot projects.
Hydropower and storage portfolio	Optimisation of existing hydropower and Samina; new options on the Rhine or in the mountains only after a feasibility assessment.

Before areas with unresolved conflicts are designated, portfolios must be assessed against identical supply objectives. Without this comparison, an overriding interest in energy use can be justified only incompletely. A definitive legal assessment additionally requires consideration of the entire procedure and the reasoned selection of reasonable alternatives.

BENEFITS AND CAPITAL COMMITMENT

2 Economic risk profile

Wind power density is not an investable cash flow. Classification into low, medium and high interest in energy use is based on 100–150, 150–200 and more than 200 W/m² at a height of 200 m (pp. 19 and 23–24). This physical metric describes the available resource. It does not incorporate complete turbine performance, construction costs, operating costs, revenues or mitigation measures.

2.1 Methodological gap in the assessment of benefits

The report states that economic assessments fall outside its scope (SEA p. 11), yet justifies greater tolerance of conflicts by a high interest in energy use and explicitly refers to economically viable operation in its wind classification (pp. 9 and 24). This decision logic is incomplete. The resource class demonstrates neither a viable net energy yield after requirements nor an appropriate balance between benefits, impacts and capital commitment.

For public electricity supply, three perspectives must also be distinguished: project returns, potential consequences for tariffs and owners, and social benefits after environmental and distributional effects. A guarantee, subsidy or internal cross-subsidy may improve the first without automatically improving the other two.

Reported potential

Area	Total turbines	Energy GWh/year
Balzers	2–3	14.5–21.8
Triesen-Vaduz	1–5	6.5–32.3
Schaan-Eschen	6–13	29.1–63.0
Schellenberg	1–3	6.5–19.4
Ruggell South	0–1	0–6.5
Ruggell North	2–3	12.9–19.4
Total according to the SEA	12–28	69.5–162.4

Source: SEA p. 56, final designations and interim results, excluding preliminary orientations. The SEA explicitly identifies these values as a theoretical upper limit without further economic, ecological, legal or social restrictions. The totals correspond to approximately 19–45% of electricity sales through the grid in 2025; this calculation by the author is neither a forecast nor evidence of self-sufficiency. The maximum figures for individual areas must not be interpreted as a turbine layout approved in its entirety.

FROM THE WIND MAP TO NET ENERGY YIELD

2.2 Energy yield quality and measurement risk

The chain determining economic performance extends beyond the resource map. The wind profile and turbulence, together with the power curve, determine turbine energy yield; wakes, technical availability, grid restrictions and protective shutdowns determine deliverable energy; its temporal profile determines achievable revenue. Deductions must not be counted twice, but must be captured in full.

Measurement reports as a robust basis for designation

LKW reports completed mast and LiDAR measurements in Schaan, Vaduz and Balzers, and measurements still under way in Ruggell.⁷ The existence of measurements does not replace independent assessment of their reliability. Before areas with unresolved conflicts are designated, complete reports, spatial representativeness, measurement heights, seasonal coverage, long-term correction and extrapolation to the relevant areas must be disclosed.

The SEA requires at least twelve months of site-specific measurements, turbulence analysis and P50/P90 energy yield forecasts only at project level (p. 24). Where high energy yields are already intended to outweigh substantial protection conflicts, this evidence comes too late. An assessment of economic plausibility must be available before designation. P50 denotes the median energy yield; P90 denotes an energy quantity that has a 90% probability of being exceeded under the model assumptions. Without robust data and an uncertainty model, neither metric provides an adequate basis for a decision.

Transparent derivation of the potential table

The rounded values on p. 56 correspond to approximately 4.85 GWh per turbine in Schaan-Eschen, 6.45 GWh in several other areas and 7.25–7.27 GWh in Balzers. Using the 7.2 MW reference turbine in the assessment framework would imply approximately 674–1,010 full-load hours, or a capacity factor of 7.7–11.5%. This is a conditional conversion, not an established turbine performance figure. Section 9 does not disclose the turbine type, power curve and loss assumptions already included in detail.

For this reason, the Government should publish the calculation chain: turbine type used, wind distribution by direction and height, energy conversion, turbine-specific losses, and area and separation constraints. Differences from figures communicated previously should be explained on a technical basis, without mixing different turbines or different definitions of energy yield.

Drobinski et al. describe the complex dynamics of foehn and valley winds in the Rhine Valley.⁸ This meteorological complexity requires site-specific assessment of wind shear, gustiness, changes in direction, air density and shutdowns in strong winds. The regional study establishes the need for such assessment; it does not quantify any loss of foehn caused by wind farms.

⁷ LKW, Wind energy, accessed 30 September 2026.

⁸ Drobinski et al. (2007), Föhn in the Rhine Valley during MAP, QJRMS 133, 897–916.

ILLUSTRATIVE ASSUMPTIONS · REAL CHF AT 2026 PRICES

2.3 Transparent model of economic viability

The following model illustrates the risk profile of a single turbine. It uses a baseline energy yield in the order of magnitude of the rounded SEA values per turbine. Investment costs, capital costs and operating expenditure are explicitly stipulated analytical assumptions. The three cases are sensitivities, not forecasts with assigned probabilities.

Assumption	Stress case	Reference case	Favourable case
Baseline energy before additional reduction	4.85 GWh/year	6.45 GWh/year	7.27 GWh/year
Additional scenario reduction	20%	10%	0%
Net energy used in the model	3.88 GWh/year	5.805 GWh/year	7.27 GWh/year
Investment including connection and contingency	CHF 18.0 million	CHF 15.0 million	CHF 12.0 million
Real discount rate	8%	6%	4%
Fixed annual operating expenditure	CHF 0.50 million	CHF 0.40 million	CHF 0.30 million
Variable costs	10 CHF/MWh	8 CHF/MWh	6 CHF/MWh
Operating life	25 years	25 years	25 years
Net decommissioning costs at the end of the operating life	CHF 1.0 million	CHF 1.0 million	CHF 1.0 million

The additional reduction serves solely as a stress assumption for restrictions not yet included in the energy yield figure used. If the original potential calculation already includes the same losses, this reduction must be removed. It is not equated with actual losses due to birds, bats or grid constraints.

Current scope of the calculation

The model calculates real, unlevered levelised costs of electricity before tax. The investment is annualised over the operating life using the real discount rate. Fixed operating costs, variable costs and discounted decommissioning costs are added. No residual value, subsidies or rising electricity prices are assumed. Constant energy yield and constant real operating costs simplify the model.

Required scope of the calculation for an investment decision

An actual investment plan must additionally include, among other things, taxes, financing, major replacement investments, declining energy yield as the turbine ages, specific lease and maintenance contracts, price hedging and liability. Environmental and distributional effects that have not been monetised must also be included in the social assessment. The investment contingency used here does not replace a technical cost review.

ENERGY YIELD AND FINANCING ARE DECISIVE

2.4 Model results and sensitivity

Model case	Net GWh/year	CHF/MWh	Swiss ct./kWh
Stress case	3.880	577	57.7
Reference case	5.805	282	28.2
Favourable case	7.270	156	15.6

Author's scenario calculation based on the assumptions in Section 2.3. This is not a project-specific cost assessment.

In the reference case, costs are approximately CHF 255/MWh without the additional 10% reduction and approximately CHF 282/MWh with it. Even this limited reduction in energy yield significantly impairs economic viability. Mitigating this risk finding requires measured net energy yields, binding cost quotations and robust revenues. Until these are available, designation must not be based on merely assumed economic viability.

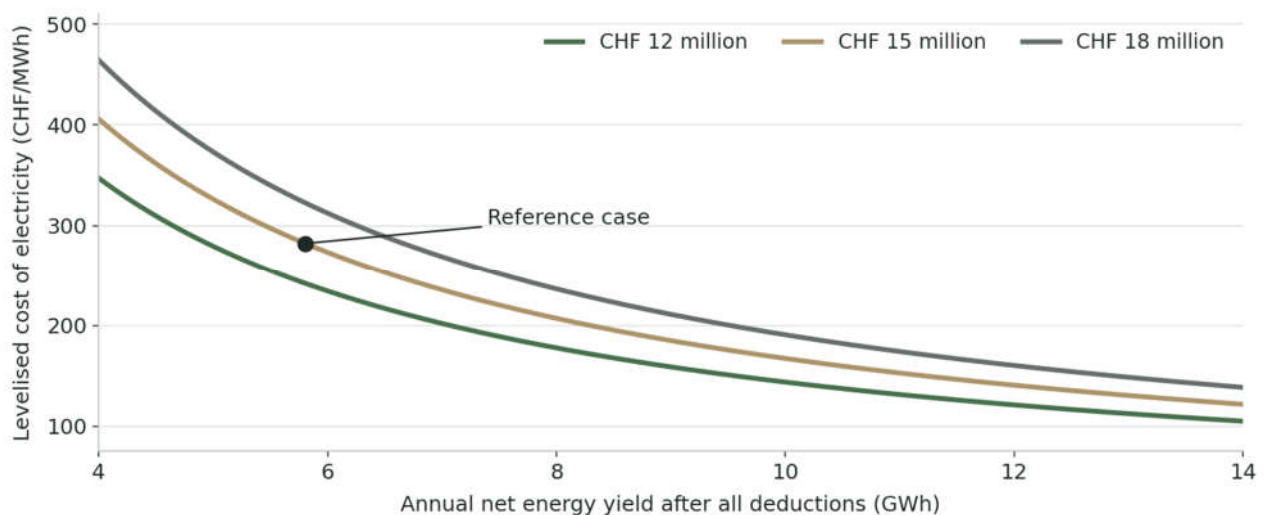


Figure 1 • Costs at different net energy yields

Author's calculation; curves for investments of CHF 12, 15 and 18 million, with the other reference assumptions unchanged and net energy after all deductions. The point marks the reference case at 5.805 GWh/year. The energy yield values shown are sensitivities, not local yield forecasts.

At an illustrative assumed real revenue of CHF 160/MWh, the reference case requires approximately 10.47 GWh/year of net energy to cover the costs shown. The planning implication is that the resource class, protection requirements and costs must be integrated before a robust claim of benefits can be made.

REVENUE IS MORE THAN AN ELECTRICITY PRICE

2.5 Electricity sales, financing and public risks

Electricity revenue must be weighted by the production profile and account for marketing costs and contractual risk allocation. The arithmetic annual price overstates project value when hours of high output coincide with low prices. Hirth describes the profile and market value risks of variable generation.⁹ Regional simultaneity, curtailment and negative prices must therefore be explicitly included in the energy yield assessment. A winter profile alone does not support promised returns.

Offtake contracts and state guarantees transfer risks to purchasers and public budgets. Price, term, counterparty, volume obligations and liability determine residual exposure. A high internal offtake price creates no social value. Easier financing must be weighed against the tariff and public budget risks assumed.

Equity returns, financing costs and total social costs must be reported separately. Risk allocation is specified in Section 2.7.

Net present value and promised returns

In the reference case, the unlevered net present value is approximately minus CHF 9.8 million at real revenue of CHF 150/MWh and minus CHF 6.1 million at CHF 200/MWh. These model results show substantial potential losses under the stated assumptions. Planning must demonstrate which measured net energy yields, costs and revenues rebut this finding. Without this evidence, committing citizens' capital or public assets lacks a robust basis.

Party bearing the risk	Matters to resolve before committing capital
Project and lenders	Conservative energy yield, debt service, spare parts, insurance coverage, construction and schedule risks.
LKW and owners	Maximum capital loss, additional capital obligations, procurement portfolio concentration and effects on distributions.
Customers and public authorities	Tariff effects, guarantees, subsidies and possible assumption of uncovered decommissioning or remediation costs.
Private citizen investors	Ranking, liquidity, fees, conflicts of interest, loss scenarios and investment duration.

Premature shutdowns, dismantling and insolvencies must be included in planning as specific technical, contractual and financial loss scenarios. Their frequency cannot be established from individual cases. Decisions therefore require independently verified failure assumptions, cost contingencies and financial security. Promises of returns based on successful reference projects must disclose their financing, subsidy and liability structures in full.

Capital should be released in stages: independent feasibility assessment, limited development capital, and final investment only with robust evidence of yields and costs. Early assessment costs should be weighed against avoided long-term losses.

⁹ Hirth (2013), The market value of variable renewables, Energy Economics 38, 218–236.

ECONOMIC COMPARISON

2.6 System value and opportunity costs

In addition to generation costs, the social assessment must capture grid expansion, balancing energy, curtailment, storage and flexibility requirements, and offset them against avoided procurement. The OECD/NEA examines substantial system costs of variable generation using modelled generation mixes.¹⁰ These cost items must not be disregarded for Liechtenstein; their local magnitude must be determined through a system calculation with sufficient temporal resolution.

German cost ranges from Fraunhofer ISE do not replace a full cost assessment for the Rhine Valley. The study examines levelised costs of electricity under specified German energy yield and financing assumptions.¹¹ For Liechtenstein, limited net energy yields, protective shutdowns, site access and infrastructure, decommissioning and additional system services must be captured in full. A favourable benchmark from other sites is not evidence of local economic viability.

Complete and consistent system costs

Reserve and flexibility requirements must be demonstrated on a binding basis for the entire development portfolio and their costs allocated accordingly. A low achievable market price may already reflect profile and simultaneity effects; the same effects must not be counted again as an arbitrary surcharge. A consistent calculation must make all additional burdens visible, including costs borne outside the individual project.

Liechtenstein requires a calculation with sufficient temporal resolution covering demand, domestic production, foreign equity interests, import opportunities and storage operation across multiple weather years and seasonal variation. Alongside annual energy, it must specifically report delivery during critical winter hours, expected unserved demand and available capacity under import restrictions. Regional wind correlation and simultaneous scarcity in neighbouring countries must be included in the stress cases.

The country's scarce resources

The economic profile extends beyond the turbine budget. Capital, grid capacity, land, landscape quality and public attention all have alternative uses. The comparison should therefore use identical investment budgets and identical supply objectives. Otherwise, the option whose additional costs are recorded outside the project under assessment gains an advantage.

Lease payments and taxes increase the revenues of individual recipients, but as transfers they do not automatically establish a net social gain. Employment promises must be adjusted for displaced activities and the imported share of turbines and services. The assessment of energy use must focus on incremental benefits after all costs and distributional effects.

Environmental effects without a robust monetary value must remain visible as a separate dimension of the decision. Statutory grounds for exclusion are not overridden by a higher return. Where conflicts permit a balancing of interests, it must be disclosed which additional energy or supply objective justifies the impact and why a less harmful alternative cannot adequately achieve that objective.

¹⁰ OECD/NEA (2019), The Costs of Decarbonisation, original study on system costs.

¹¹ Kost et al. / Fraunhofer ISE (2024), Stromgestehungskosten Erneuerbare Energien.

ADDITIONAL SYSTEM ASSESSMENT

2.7 Financing and supply under stress

Financing costs and risk transfer

McKinsey estimates the German energy system's investment requirements over ten years at EUR 780–1,035 billion and emphasises the influence of financing on total costs. The analysis covers electricity, heat, gas and hydrogen infrastructure.¹²

For each development portfolio, capital requirements, costs of equity and debt, and the parties bearing price, volume, construction and failure risks must be disclosed. Guarantees and secured revenues reduce an investor's risk only to the extent that another party assumes it. A resulting increase in project returns must not be presented as an additional social benefit. Tariff and public budget risks must be reported in full, including in the stress case.

Import availability during scarcity hours

McKinsey's 2026 electricity market report models different levels of German import dependence through 2035 and possible price effects on neighbouring countries. Its annual electricity system costs of EUR 87–90 billion must be distinguished from the investment volumes in the separate financing analysis. Adding them together without clarifying the boundaries of the cost categories would be methodologically invalid.¹³

The Liechtenstein stress test should include simultaneous scarcity in neighbouring countries, rising demand, power plant outages, changes in generation capacity and restricted cross-border transmission. It must report available import capacity, procurement costs and supply shortfalls during critical winter hours. Local wind production must be matched against these hours; annual energy and foreign equity interests alone do not demonstrate firm delivery.

Separate evidence of grid services

ENTSO-E's final report on the Iberian blackout of 28 April 2025 describes the interaction of heterogeneous and variable energy sources, oscillations, shortcomings in voltage and reactive power control, and generation disconnections.¹⁴ The case illustrates the importance of stability functions with assured availability. For development in Liechtenstein, these capabilities and their costs must be demonstrated in advance; annual energy alone does not describe compatibility with the grid.

Grid operators and project developers must jointly demonstrate how voltage control, reactive power provision, frequency support and system restoration will be ensured within the development portfolio. Technical capabilities, assured availability, additional investment and operating costs, and the parties bearing them must be reported. Required black start resources must be secured and financed on a binding basis within the overall system.

¹² Overlack et al. / McKinsey (September 2026), financing as a lever to reduce energy system costs.

¹³ McKinsey (2026), Strommarktreport 2026, official summary dated 26 February 2026.

¹⁴ ENTSO-E (20 March 2026), final report on the Iberian blackout of 28 April 2025, official summary.

SIX AREAS · DIFFERENTIATED ASSESSMENT

3 Spatial and other risk profiles

The SEA's area descriptions (pp. 53–55), maps and species annex show the concentration of material site conflicts. Areas where favourable modelled wind conditions clash with several protection interests are particularly critical. The following assessment identifies the questions that must be resolved before designation.

Area and SEA finding	Assessment priority
Balzers: high interest in energy use; predominantly final designation. Species conflicts, infrastructure and neighbouring water interests (pp. 53–54).	Very high need for clarification. Justify the departure from the species annex's most critical area finding; include shutdowns, the heliport and cumulative effects with St. Gallen.
Triesen-Vaduz: fragmented areas; final designations and interim results because of soil and groundwater (p. 54).	High need for clarification for individual subareas. Examine individual buildings, eagle owl habitat use, the land use balance, communication and neighbouring Swiss planning.
Schaan-Eschen: moderate wind conditions; up to 13 turbines in the theoretical potential; soil and wildlife corridors (pp. 54, 56).	High need for economic and cumulative assessment. Lower energy yield per turbine coincides with the largest possible turbine fleet; assess corridors and interacting wakes.
Schellenberg: hilltop location, limited area, greatest visibility over long distances; ecological structural features (pp. 54–55).	High need for clarification of landscape and site issues. Fewer known bird conflicts do not replace an overall assessment; specify visibility, turbulence and habitats.
Ruggell South: a small area potentially accommodating one turbine; visual relationship with Schellenberg (p. 55).	Joint assessment required. Assess landscape, species movements and operating requirements together with Schellenberg; a small number of turbines does not imply limited overall conflict.
Ruggell North: favourable wind conditions; a mixture of final designation, interim result and preliminary orientation; border region conflicts (p. 55).	Very high need for clarification. Integrate the stork colony, wetland, bird migration, soil and Swiss and Austrian connections with net energy yield.

These priorities identify the strategically decisive conflicts at area level. Designation of individual subareas requires transparent delineation and its own justification. Favourable wind conditions rebut neither species conflicts nor landscape or environmental exposure risks. As long as this link remains unresolved, the resource indicator does not substantiate site suitability.

PROTECTION REQUIREMENTS CHANGE THE BUSINESS CASE

3.2 Birds and bats as permitting risks

The accompanying species report is the strongest local evidence of an increased need for clarification. It is based on existing data and expert discussions, not its own field surveys; a low density of records is explicitly not equated with low species richness (Annex A pp. 4–5 / PDF pp. 67–68).¹⁵

Balzers: nateco describes the area as the site with the greatest potential for conflict in the study area, with national significance and high to elevated levels of conflict. Planning there should be avoided wherever possible; otherwise, extensive protection measures and detailed analyses would be necessary (Annex A pp. 21–23 / PDF pp. 84–86). The predominantly final designation on p. 54 therefore requires particularly clear justification for each subarea. The difference between the larger species assessment area and the final suitability perimeter must be disclosed cartographically.

Ruggell: the annex considers frequent shutdowns triggered by detection systems and energy yield losses that call economic viability into question to be possible; it also mentions potential relocation of the stork colony (Annex A pp. 13–14 / PDF pp. 76–77). Relocation is not a standard measure that can be applied without prerequisites. Its permissibility, effectiveness, costs and ecological consequences would require separate assessment. Project energy yield achievable only by relocating a protected asset must not be counted as a benefit involving few conflicts.

For migrating small birds, nateco describes the valley as a whole as prone to conflicts; for bats, knowledge gaps concern activity at considerable heights (Annex A pp. 24–27). Using radar measurements in other Alpine valleys, Hirschhofer et al. confirm their importance as migration corridors and emphasise dependence on local weather and topography.¹⁶

More stringent assessment requirements arising from international findings

Garvin, Simonis and Taylor find species-specific relationships between rotor size, ground clearance and mortality in North American data. Larger rotor diameters are associated with higher mortality rates in the bird species studied.¹⁷ Kumara et al. document collision and habitat risks for birds and mammals at Indian sites.¹⁸ For Liechtenstein, these findings imply assessments specific to turbines and species; local mortality figures must be established using local data.

Before designation, complete activity periods, flight and hunting areas, effective seasonal shutdown regimes and the resulting energy yield losses must be assessed. Official collision records such as those of the Brandenburg State Environment Agency document impacts on birds and bats.¹⁹ Robust monitoring must adjust for search effort, detectability and carcass removal. The energy yield calculation must be completed only after protection requirements have been taken into account.

¹⁵ nateco AG (2025), Annex A of the SEA, particularly internal pp. 4–5, 13–14, 21–27.

¹⁶ Hirschhofer et al. (2024), High-intensity bird migration along Alpine valleys, RSEC 10, 360–373.

¹⁷ Garvin, Simonis and Taylor (2024), Does size matter?, Biological Conservation 291, 110474.

¹⁸ Kumara et al. (2022), Responses of birds and mammals to long-established wind farms in India.

¹⁹ LfU Brandenburg, effects of wind turbines on birds and bats.

PRECAUTION BASED ON ROBUST EVIDENCE**3.3 Health, noise and operational safety**

The SEA uses a distance of 300 m from residential, mixed-use and core zones; beyond this distance, the strategic health classification is “suitable” (p. 26). At the same time, it states that evidence of compliance with the Noise Protection Ordinance (LSV) and individual occupied buildings are to be considered only at project level (p. 27). This distance is therefore neither evidence of an absence of health risks nor a universally safe distance for turbines of different sizes.

Before designation, a representative assessment of environmental exposure is required for the reference dimensions. It must include individual occupied buildings, night-time operation, stable atmospheric stratification in the valley, low-frequency components, amplitude modulation and combined noise from multiple sources. Shadow flicker, aviation lighting and visual dominance must be assessed separately. The WHO guidelines explicitly address wind turbine noise as a matter of health-related precaution.²⁰

Infrasound

Marshall et al. found no corresponding deterioration in 37 healthy adults under simulated infrasound exposure compared with sham exposure.²¹ This finding applies to the study design used; the actual combination of audible noise, low-frequency components, amplitude modulation and long-term operation remains to be assessed for each site. A 72-hour laboratory study does not replace an assessment of decades of residents' exposure.

Godono et al. judge the existing research on exposure to wind turbines and sleep disorders insufficient for causal conclusions.²² This evidence gap does not support blanket health clearance for the planned sites. Objective exposure data, validated assessments of sleep quality and verifiable intervention thresholds are required. A specific cause involving infrasound must not be assumed without evidence.

In a preprint that has not been peer reviewed, Dastan et al. report changes in microvascular vasomotion in mice following repeated exposure at 1 Hz and 100 dB.²³ The finding establishes a need for further research into biological mechanisms. Replication and comparison with real exposure among residents are required; there is no clinical evidence in humans. Strategic precaution therefore continues to depend on robust exposure and operating limits and future international studies.

Technical safety risks

Ice throw or falling ice, fire, component failure and conflicts with traffic or aviation require binding safety evidence. For Balzers, the SEA already identifies the heliport and transmission infrastructure (p. 54). Safety zones, warning and shutdown systems, maintenance access, emergency response arrangements and financial coverage must be specified plausibly before designation. Unresolved hazard areas must not be replaced by general assurances of operational safety.

²⁰ WHO Regional Office for Europe (2018), Environmental Noise Guidelines for the European Region.

²¹ Marshall et al. (2023), 72 Hours of Simulated Wind Turbine Infrasound, EHP 131(3), 037012.

²² Godono et al. (2023), Association between exposure to wind turbines and sleep disorders, IJHEH 254, 114273.

²³ Dastan et al. (2026), Repeated Infrasound Exposure Alters Vasomotion in Mice, preprint v1, not peer reviewed.

LOCAL ENVIRONMENTAL EFFECTS MUST BE ASSESSED**3.4 Local climate, soil and water**

The SEA treats air and climate predominantly as supporting energy use; it does not provide for a separate climate sensitivity map (p. 42).

Microclimate

Under stable night-time conditions, Weerappulli Hewage, Wanner and Mauder model warming near the ground and increased soil moisture losses; daytime effects differ.²⁴ Wang, Li and Liu report drying of surface soil at Chinese grassland sites.²⁵ These findings challenge an exclusively positive assessment of climate effects. The nature and magnitude of consequences in the Rhine Valley must be determined locally; results from other regions do not provide a direct forecast of crop losses.

Before designation, cold air drainage, inversions, fog, evaporation and soil water must be examined with and without development. The complex foehn dynamics of the Rhine Valley increase the demands on modelling. A combination of meteorological reference data, coupled flow models and measurements in sensitive agricultural areas is required. An untested assumption that local climate effects are insignificant does not support the balancing of interests.

Soil as a scarce productive asset

The SEA acknowledges the high soil fertility of the valley and soil losses that are irreversible or only partly reversible (pp. 36–37). This must lead to binding consequences for site selection. The frequent classification as an interim result must not be converted into final designation through a subsequent blanket promise of land restoration.

The land use balance must include foundations, permanent access roads, crane platforms and temporary logistics areas. Compaction, drainage, fragmentation and the quality of restoration must be assessed. The economic loss is not limited to the lease agreement. Agricultural productivity and flexibility of future use may be affected.

Water interests

For groundwater, the Rhine corridor, water retention and flood protection, the SEA contains exclusions and requirements for further assessment (pp. 39–40). A transparent joint assessment is additionally required of construction materials and operating substances, foundation location, flood events and neighbouring river restoration and widening projects. New hydropower options are subject to the same requirements concerning aquatic ecology and flood protection.

The relevance of these risks varies spatially. Before particularly sensitive subareas are designated, a decision should be made on which uncertainty is acceptable and which finding would exclude an area. Monitoring after commissioning does not replace this decision.

²⁴ Weerappulli Hewage, Wanner and Mauder (2026), Wind Turbines, Microclimate and Soil Moisture, BLM 192, 50.

²⁵ Wang, Li and Liu (2023), Wind farms dry surface soil in temporal and spatial variation.

CONTRACTS AND FINANCIAL SECURITY RATHER THAN ASSURANCES**3.5 Materials, decommissioning and life cycle**

A wind turbine commits steel, concrete, copper, composites and technical components for decades. In the overall assessment, manufacturing, transport, site access and infrastructure, operation and decommissioning must be related to the net energy realistically generated. Largely emission-free operation must not be equated with an emission-free life cycle.

Disposal risk and technological development of rotor blades

In 2017, Liu and Barlow projected approximately 43 million tonnes of cumulative global rotor blade waste by 2050.²⁶ This long-term projection illustrates the scale of the disposal challenge. Composites require technically assured and financially viable treatment routes; general recycling promises do not resolve project-specific liability and cost risks.

Moradi and Yang examine a thermal recycling model validated at a pilot plant and its scaling.²⁷ Pilot validation assures neither available industrial capacity nor economically viable disposal of future rotor blades. For Liechtenstein projects, storage, binding offtake routes, transport, treatment costs, material quality and fallback solutions must be demonstrated and financially secured before investment.

Substance releases and PFAS risks

ECHA explicitly includes the energy sector in the PFAS restriction process and describes the persistence, environmental spread and difficulty of remediating PFAS contamination.²⁸ Material composition, potential releases and subsequent costs are therefore life cycle risks relevant to the assessment. Emissions and exposure must be determined for specific wind turbines. PFAS, bisphenols and microplastics each require their own substance pathways and mechanisms of impact to be assessed.

Before investment, lists of materials and coatings, robust abrasion and release data, substitutes, maintenance procedures and evidence of disposal arrangements must be disclosed. The costs of monitoring, remediation and substitution must be allocated to the responsible party. Quantities stated in kilograms without a transparent measurement method do not support a risk assessment. Use of rare earths must be disclosed for the specific generator proposed.

Decommissioning liability

Before construction begins, independently calculated and regularly adjusted financial security is required for dismantling, treatment of foundations, contamination, land restoration and disposal. An accounting provision in a project company is not an equivalent guarantee. Security must remain effective in the event of a change of ownership, insolvency or premature shutdown.

Decommissioning costs and potential revenues from materials must be reported separately. Reuse or “repowering” does not automatically reduce the burden. It may require a new planning and technical decision. The original assessment of economic viability should therefore not rely on unsecured continued operation beyond the assumed operating life.

²⁶ Liu and Barlow (2017), Wind turbine blade waste in 2050, Waste Management 62, 229–240.

²⁷ Moradi and Yang (2026), Wind Turbine Blade Thermal Recycling, Sustainability 18(12), 5859.

²⁸ ECHA (2025/2026), PFAS restriction process and substance risks; the energy sector is explicitly included.

WHO BENEFITS · WHO BEARS THE CONSEQUENCES

3.6 Landscape, property and distribution

Turbines with a total height of up to 285 m change the perception of a geographically confined valley. The SEA recognises Schellenberg's particular visibility over long distances and its visual relationship with Ruggell South (pp. 54–55). Assessment at individual project level may underestimate the changes caused by several Liechtenstein and Swiss wind energy areas.

Cumulative effects

Adopting the highest individual protection interest under Section 8.1 (SEA p. 50) does not capture the full cumulative effect. Several moderate impacts can together have substantial consequences even if no individual category already leads to exclusion. A simple overlay of maps then underestimates the overall burden relevant to the decision.

Combined viewsheds, night-time aviation lighting, noise, flight corridors, habitat fragmentation, roads and grid infrastructure must be added. Swiss wind energy areas are already shown on the Spatial Plan map (p. 53). Their different planning basis does not remove the technical need for a joint assessment of the border region.

Property and asset risks

Using a quasi-experimental approach, Gibbons identifies negative effects of visible wind farms on property prices in England and Wales.²⁹ This finding requires a local assessment of consequences for assets and residential quality. Visibility, turbine configuration, market structure and existing impacts determine the magnitude; a uniform percentage discount for Liechtenstein cannot yet be derived from it. Nevertheless, this risk must be explicitly included in the distributional assessment.

A local study should use transaction data, visibility relationships and suitable comparison areas. Where landscape or noise impacts have already been monetised through property prices, the same welfare losses must not be added again in full as a separate damage item. Non-tradable natural assets remain independent of this consideration.

Citizens' capital

Citizen investment schemes distribute capital risks among private investors. They replace neither protection for residents who do not participate nor an equitable distribution of burdens. Lease payments and returns accrue to particular individuals; noise, visual impacts and restrictions on use may affect others. Investment advice and public participation must be separated organisationally; loss scenarios must be transparent before subscription.

Governance

The consultation notice names LKW as chair of the operational SEA team. Participation by a potential developer in the assessment of its own energy use data requires an independent second review. Data access, roles, conflicts of interest and reasons for decisions must be documented transparently. Institutional participation does not replace independent validation of assumptions.

²⁹ Gibbons (2015), *Gone with the wind*, JEEM 72, 177–196; working paper in the LSE repository.

SPECIFIC PREREQUISITES FOR A DECISION

4 Procedural proposals and request for amendments

It is requested that the draft be supplemented or revised in the following respects before its final incorporation into the National Spatial Plan. These requests address the strategic decision; detailed planning and subsequent statutory evidence remain necessary.

Requested amendment	Evidence before final designation
1 · Validate the interest in energy use	Publish wind data, the derivation of the energy figures on p. 56, the seasonal profile and net energy yield after protection requirements; assess the economic plausibility of areas with unresolved conflicts.
2 · Reassess areas with unresolved conflicts	For Balzers and Ruggell North, justify the treatment of the species annex for each subarea. Reflect strategically decisive unresolved findings through interim result, preliminary orientation or exclusion.
3 · Assess the border region and cumulative effects	Jointly assess several suitable areas and neighbouring projects with regard to landscape, species, noise and infrastructure; demonstrate grid services and import availability during scarcity hours.
4 · Specify health and safety requirements	Conduct a representative exposure and safety assessment for the reference dimensions, including individual buildings, night-time conditions and operating limits.
5 · Make alternatives comparable	Add a realistic reference case without additional wind energy designation and energy portfolios with the same annual energy, winter energy and supply objectives.
6 · Secure liability and monitoring arrangements	Specify independent data verification, public reports, intervention thresholds and financial security for decommissioning and remediation that remains effective in insolvency; disclose financing costs, guarantees and residual risks for each party bearing them.

Assessment requirements and consequences for decisions

For each material unresolved issue, responsibility, data requirements, deadline, costs and the consequences for the decision must be recorded. An adverse finding concerning species or environmental exposure must be capable of triggering adjustment of the perimeter or abandonment. Reduced production after protection requirements must be included in the renewed assessment of benefits.

The SEA's monitoring framework (pp. 58–59) is adequate only when accompanied by assessment across areas, specific trigger thresholds, verifiable protection effectiveness and financial coverage for additional requirements. The project sponsor's responsibilities must be combined with independent oversight. Monitoring after commissioning must not legitimise unresolved strategic site conflicts.

COMPARE ALTERNATIVES BY BENEFIT AND MATURITY

4.2 Diversified energy portfolio

A diversified energy portfolio must be assessed systematically before additional land is committed to wind energy. It must meet the same annual, winter and scarcity objectives and disclose all costs. Existing building surfaces, demand flexibility, and hydropower and storage infrastructure offer distinct opportunities whose potential is inadequately captured by an assessment of alternatives spatially restricted to wind energy.

Option	Contribution	Key assessment constraint
Efficiency and demand management	Lasting savings and reduction of winter demand peaks; use of existing installations.	Achievable potential, implementation costs, comfort and contractually available flexibility.
Rooftop and façade PV	Decentralised generation on existing buildings; orientation towards winter output is possible.	Winter profile, self-consumption, roof condition, grid absorption capacity, financing and competing uses of space.
Small vertical-axis wind turbines	Supplementary generation on demonstrably suitable, exposed buildings or commercial sites.	Measurable energy yield, turbulence, vibration, noise, structural integrity and maintenance; begin with a pilot.
Existing and new hydropower	Controllable contributions depending on water availability; potential additional energy generation.	River flow, sediment transport, aquatic ecology, concessions, flood protection and cross-border coordination.
Pumped storage and other storage	Time shifting and flexibility; supply during defined scarcity hours.	Charging energy, efficiency, power, storage volume, costs and sites compatible with nature protection.
Procurement and equity interests	Diversification by region and technology; securing energy and prices.	Import capacity, simultaneous bottlenecks, contractual and counterparty risks.

As a central provider of essential public services in Liechtenstein, LKW already describes a portfolio of hydropower, PV, procurement and other assessed options.³⁰ The alternative therefore consists of verifiable prioritisation of additional investment and further development of existing infrastructure rather than the creation of an entirely new system.

Additional investments should be prioritised by benefit per franc committed, delivery during critical hours and remaining protection conflicts. Decentralised options on buildings can avoid additional impacts on soil and open landscapes. Large wind turbines must demonstrate their incremental benefit over these alternatives, including site infrastructure, protection and system costs.

³⁰ LKW, Our electricity future, accessed 30 September 2026.

PILOT · MEASURE · SCALE ONLY WHERE SUITABILITY IS PROVEN**4.3 Decentralised solutions and vertical rooftop wind turbines**

Vertical-axis rooftop wind turbines should be tested specifically as a decentralised supplement. The use of existing building surfaces and changing wind directions establishes a concrete avenue for assessment. Measurable net energy yields, noise, structural integrity, vibration and life cycle costs determine suitability. A limited pilot makes these questions verifiable with a manageable capital commitment.

Fields et al. describe the specific technical and economic requirements of wind turbines on buildings.³¹ The U.S. Department of Energy identifies turbulence, vibration transmission and additional costs of typical rooftop installations.³² These requirements must be incorporated into pilot planning. Site measurements and independent analysis enable a verifiable decision before broader deployment commits capital.

An economically meaningful pilot

A small number of exposed commercial or infrastructure roofs initially appear suitable, provided there is sufficient separation from sensitive uses and good maintenance access. Before purchase, the wind profile at the actual installation point, building and roof structural integrity, vibration isolation, structure-borne noise and certification must be assessed. Vertical-axis and other small wind concepts should be compared using actual performance data, not manufacturers' rated capacity alone.

The pilot should cover at least one complete annual cycle and report net energy after accounting for the equipment's own consumption, availability, maintenance and shutdowns. Comparison with additional PV on the same surface is essential. Deployment should proceed only if energy yield, safety and full costs compare favourably with the best available alternative for the building.

PV and demand flexibility as a broader decentralised contribution

Rooftop and façade PV on suitable existing buildings can use available surfaces. Façades designed for winter output and steeper orientations must be assessed separately for energy yield, shading and electricity value. Storage, heat pump control and flexible commercial loads can increase self-consumption and system benefits. Investment, replacement needs and the temporal limits of storage must also be considered transparently.

For additional resilience, building generation, suitable inverters, storage, protection equipment and critical loads must be planned together. Townscape, neighbours and permitting are part of the site assessment. Small wind turbines must be evaluated using actual net energy yields and full costs; manufacturers' rated capacities are insufficient.

It is recommended that building surfaces be used systematically, flexibility be developed and vertical rooftop wind turbines be tested through measurements at suitable sites. These contributions should be combined into an energy portfolio and scaled according to measured performance. Only such a comparison reveals what additional need for large wind turbines remains.

³¹ Fields, Oteri, Preus and Baring-Gould (2016), Deployment of Wind Turbines in the Built Environment, NREL.

³² U.S. Department of Energy, Frequently Asked Questions on Small Distributed Wind Systems, rooftop installations.

DISTINGUISH ENERGY GENERATION FROM STORAGE**4.4 Rhine hydropower and pumped storage**

Hydropower from the Rhine belongs in a long-term energy mix coordinated across borders. Technically and ecologically viable concepts must be examined, including their water flows, sediment loads, fish passage, residual flow requirements and effects on flood protection and river restoration projects. Use of a border river requires coordination; an energy potential figure alone does not establish that a project can be permitted.

River flow, usable head, bedload and suspended solids determine the availability of Rhine hydropower. LKW considers hydrokinetic power buoys uneconomic under current conditions. This finding requires a differentiated assessment of concepts rather than restriction to power buoys. Concession requirements and cross-border responsibilities must be clarified early; technological and civil engineering alternatives must be compared using current full costs.

Samina as a pilot facility

Samina has had pumped storage infrastructure since its conversion in 2015.³³ Optimisation and any technically and ecologically feasible expansion should be examined as a priority. Existing infrastructure provides a concrete starting point for additional flexibility and comparison with new impacts and long-term capital commitment.

New pumped storage options in the mountains must be assessed by storage volume, head, charging and discharging power, water availability, geology, natural hazards, grid connection and impacts. A lower or higher reservoir alone does not create economically viable storage. Charging energy must be available both financially and physically.

Gravity as a storage principle

Pumped storage and other gravity storage systems return part of the energy previously supplied. Their benefit lies in flexibility and time shifting; losses remain. For context, a purely hypothetical usable water volume of 100,000 m³ with a head of 500 m and a discharge efficiency of 90% provides approximately 123 MWh. At an output of 25 MW, this is just under five hours. With an assumed round-trip efficiency of 80%, approximately 153 MWh of charging energy would be needed. This calculation does not describe an identified site in Liechtenstein.

Such storage can shift energy over hours but cannot by itself cover a winter shortfall lasting several weeks. That would require substantially greater quantities of energy, ongoing inflows or additional procurement. Storage systems using raised solid masses are also subject to this energy balance.

A joint feasibility calculation is recommended for existing hydropower, Samina, potential new mountain storage and Rhine options. The comparison should use the same capital budget and the same critical supply hours as additional wind energy.

³³ Government (2023), Klimastrategie Liechtenstein 2050, printed p. 22 / PDF p. 24: Samina conversion in 2015.

MORE EVIDENCE BEFORE LONG-TERM DESIGNATION

4.5 Conclusion and recommendation

In its present form, the SEA report does not provide an adequate basis for the final designation of wind energy areas with unresolved conflicts. It does not integrate the wind resource, production after protection requirements, electricity value and economic risk into a coherent assessment of energy use. General development targets and requirements for later assessments do not close this strategic gap.

For Balzers and Ruggell North in particular, favourable wind conditions alone are insufficient as the principal measure of benefit. The species annex describes high local conflicts and, in Ruggell, potentially substantial shutdowns. These may change the assessment of benefits. For Schaan-Eschen, comparatively lower energy figures per turbine coincide with the greatest theoretical development potential. Schellenberg's pronounced visibility over long distances requires separate weighting.

The theoretical 69.5–162.4 GWh/year is not an assured contribution to development or supply. The SEA itself identifies it as an upper limit without further restrictions. The planning provides an adequate basis for a decision only when supported by conservative net energy yields, temporal production profiles and an independent economic assessment of the areas with unresolved conflicts.

Rejection of designation without amendment is already supported by documented local species conflicts, unresolved exposure and local climate issues, and substantial economic sensitivities. A blanket demonstration of harm for every wind turbine is not required. What matters is that material risks and the claimed overriding benefit must be sufficiently clarified before an advance spatial planning decision. Until this is done, designation lacks adequate substantive support.

A viable energy mix as a better basis for the decision

Priority should be given to assessing a diversified portfolio of efficiency, demand management, rooftop and façade PV, suitable decentralised wind options, hydropower, storage and secured procurement. Vertical-axis rooftop wind turbines belong in this comparison as a limited pilot option evaluated through measurements. Additional areas for large wind turbines must first demonstrate their benefit relative to such a portfolio.

Hydropower from the Rhine merits a renewed feasibility assessment open to different technologies, fully accounting for river flow, sediments, ecology and coordination across borders.

Pumped storage in Liechtenstein's mountains, or optimisation of Samina, can create valuable flexibility. Harnessing gravity stores energy; it does not replace additional generation.

It is recommended that the draft be revised before final designation of the areas with unresolved conflicts, that the requested evidence be independently assessed and that alternatives be compared against identical supply objectives. Until then, areas with unresolved strategic issues must be deferred or excluded. Public assets and citizens' capital must not be committed through an advance spatial planning decision to an inadequately substantiated benefit.

TRANSPARENCY OF CALCULATIONS

Annex A Calculation methodology and model limitations**A.1 Real levelised costs of electricity**

All monetary amounts are real CHF at 2026 prices. No conversion from EUR has been made. The real discount rate is consistent with constant real costs and revenues. The operating life is 25 years. Annual energy remains constant in the simplified model.

The capital recovery factor is the discount rate divided by the difference between one and the discount factor over 25 years. The initial investment plus the present value of net decommissioning costs is annualised using this factor. Annual fixed operating costs and variable costs are added. The total is divided by annual net energy. In the reference case, the factor is 0.07823; annual fixed total costs, including annualised capital and decommissioning, are approximately CHF 1.592 million.

The unrounded model results are: stress case 576.98, reference case 282.18 and favourable case 156.23 CHF/MWh. Rounding in the presentation may produce small differences. CHF 100/MWh corresponds to 10 Swiss centimes/kWh.

A.2 Net present value and energy yield threshold

The unlevered net present value is the sum of annual net cash flows discounted at the real rate, less the initial investment and discounted decommissioning costs. Annual net cash flow is net energy multiplied by revenue after variable costs, less fixed operating expenditure. At CHF 150/MWh, this cash flow is approximately CHF 0.424 million/year in the reference case.

The net energy required to cover costs is the annual fixed total cost divided by the assumed electricity revenue less variable costs. At CHF 160/MWh, this produces the threshold of 10.47 GWh/year shown in Section 2.4. Subsidies, taxes, additional replacement investments and financing alter this threshold.

A.3 Physical conversions

Full-load hours are annual energy in MWh divided by rated capacity in MW; the capacity factor is this value divided by 8,760 hours. The conversion of the SEA values to 7.2 MW stated in the text explicitly assumes this reference turbine type and does not replace a measured energy yield forecast.

The hypothetical storage energy is calculated from a water density of $1,000 \text{ kg/m}^3$, gravitational acceleration of 9.81 m/s^2 , usable volume, head and discharge efficiency, and converted from joules to MWh. One MWh corresponds to 3.6 billion joules. Discharge efficiency and the round-trip efficiency of a charging and discharging cycle are different quantities.

A.4 Limits of interpretation

The model cases illustrate the economic effects of central uncertainties; they do not contain statistically estimated probabilities of occurrence. Before capital is committed, independent energy yield data, binding quotations, protection requirements and contracts must be used. The absence of a project-specific calculation is itself an unresolved prerequisite for a decision, not a reason to discount the risk profile.

SUBSTANTIATE RISKS AND SPECIFY CONSEQUENCES FOR DECISIONS

Annex B Risk evidence and assessment requirements

The assessment draws on local technical findings, original studies and official documents. Journalistic articles serve as research leads. Data gaps must be translated into binding assessment requirements. The following risk areas identify the evidence missing before long-term designation or capital commitment.

Risk area	Evidence and consequences for the decision
Health and noise	Assess actual exposure and long-term burdens for each site. Short-term experiments and unresolved questions of causality do not replace assessment of the residential areas affected.
Microclimate and soil moisture	Incorporate warming that depends on atmospheric stability and findings of drying into local modelling. Environmental consequences that have not been assessed must not be treated as insignificant.
Birds and bats	Assess activity, flight areas and mortality risks for individual species. Binding protective shutdowns must be incorporated into net energy yield and the assessment of sites.
Rotor blade disposal	Secure available treatment capacity, storage, offtake agreements, costs and fallback routes. Pilot processes and technical possibilities do not replace evidence of funded disposal arrangements.
PFAS and other substance releases	Disclose materials, abrasion, exposure pathways and remediation liability. The ECHA documents establish the need for a specific assessment of materials and the life cycle.
Shutdown and capital loss	Examine technical failures, premature decommissioning and insolvency as loss scenarios. Binding contingencies and financial security must remain effective even without continued operation.
Transferability of studies	Exposure, site and mechanism of impact must be relevant to the specific turbine. Non-comparable offshore noise studies do not replace an exposure assessment in the Rhine Valley.
Data quality and independent assessment	Disclose original findings, model assumptions and uncertainties; identify preprints. A developer's participation requires independent validation of data.

The documented conflicts and missing evidence require a critical reassessment. Data requirements, parties bearing risks, protection requirements and consequences for exclusion must be specified on a binding basis before designation. Unresolved site and long-term questions must not be treated as evidence of an absence of risk.

Footnote references

Complete references for the numbered footnotes. Access and assessment date: 30 September 2026. The studies are used according to their actual subject matter and transferability.

1. Government of the Principality of Liechtenstein (2026). Strategische Umweltprüfung (SUP) zur Festlegung von Windeignungsgebieten im Landesrichtplan des Fürstentums Liechtenstein. Planungs- und Umweltbericht, draft dated 30 June 2026, 92 PDF pages including Annex A. The assessment is based on the complete PDF version provided. [LLV · SEA draft](#)
2. Liechtenstein National Administration, Office of Environment. Energienutzung. Official information on wind energy, hydropower and the SEA procedure; accessed 30 September 2026. [LLV · Energy use](#)
3. Liechtenstein National Administration. Geoportal, Spatial Planning theme. Dynamic mapping service; a dated export of the relevant geodata is required for a reproducible detailed assessment. [Geoportal · Spatial planning](#)
4. Government of the Principality of Liechtenstein (2026). Entwurf zum Planungs- und Umweltbericht der Strategischen Umweltprüfung (SUP) zur Festlegung von Windeignungsgebieten im Landesrichtplan geht in die öffentliche Konsultation. Media release dated 14 July 2026; consultation deadline 30 September 2026. [Government · Consultation](#)
5. Principality of Liechtenstein. Act of 15 March 2007 on Strategic Environmental Assessment (SUPG), LGBI. 2007 No. 106, LR 814.04, consolidated version dated 1 January 2013. In particular, Articles 8–10 on the environmental report and Article 16 on monitoring. [Gesetze.li · SUPG](#)
6. Government of the Principality of Liechtenstein (2026). SUP Wind – Untersuchungsrahmen, version dated 26 March 2026; according to the environmental report, adopted on 31 March 2026. Reference turbines and dimensions: pp. 11–12 of the printed pagination, PDF pp. 12–13. Vestas V172: 7.2 MW, hub height 199 m, total height 285 m. [LLV · Assessment framework](#)
7. Liechtensteinische Kraftwerke. Windenergie. Information on completed mast and LiDAR measurements in Schaan, Vaduz and Balzers, and the measurements still under way in Ruggell; financing and potential citizen investment. Accessed 30 September 2026. [LKW · Wind energy](#)
8. Drobinski, P. et al. (2007). Föhn in the Rhine Valley during MAP: A review of its multiscale dynamics in complex valley geometry. Quarterly Journal of the Royal Meteorological Society 133, 897–916. DOI: 10.1002/qj.70. Primary meteorological research on complex valley and foehn dynamics. DOI · [Drobinski et al.](#)
9. Hirth, L. (2013). The market value of variable renewables. Energy Economics 38, 218–236. DOI: 10.1016/j.eneco.2013.02.004. Peer-reviewed study of profile and simultaneity effects and the relative market value of variable generation. DOI · [Hirth 2013](#)
10. OECD Nuclear Energy Agency (2019). The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables. OECD Publishing, Paris. DOI: 10.1787/9789264312180-en. Model-based analysis of generation and system costs; local cost levels must be determined separately. [OECD/NEA · Original study](#)
11. Kost, C., Müller, P., Sepúlveda Schweiger, J., Fluri, V. and Thomsen, J. / Fraunhofer ISE (2024). Stromgestehungskosten Erneuerbare Energien. Study dated July 2024, particularly methodology and cost assumptions. LCOE comparison for Germany; not a local full cost assessment. [Fraunhofer ISE · Original study](#)
12. Overlack, S. et al. / McKinsey (September 2026). It's the money, stupid – Finanzierung als Hebel zur Senkung der Energiesystemkosten. Energiewende-Index September 2026. Original analysis of German investment requirements and financing structures. [McKinsey · Original analysis 2026](#)
13. McKinsey (2026). Strommarktreport 2026. Official summary of results dated 26 February 2026. Modelled system costs and import dependence through 2035; scenario results for Germany. [McKinsey · Electricity market report 2026](#)

14. ENTSO-E (2026). Expert Panel Final Report on the 28 April 2025 Blackout in Spain and Portugal. Official summary of results dated 20 March 2026, with a reference to the final report. Investigation of specific causes and measures for system stability. [ENTSO-E · Final report 2026](#)
15. nateco AG (2025). Vögel und Fledermäuse – SUP Windenergie Liechtenstein. Technical assessment basis, Version V4 dated 27 November 2025, commissioned by the Government. Annex A of the SEA draft: PDF pp. 64–91. Internal page n corresponds to PDF page n + 63; the annex ends on p. 28 despite some inconsistent statements of the total page count.
16. Hirschhofer, S., Liechti, F., Ranacher, P., Weibel, R. and Schmid, B. (2024). High-intensity bird migration along Alpine valleys calls for protective measures against anthropogenically induced avian mortality. *Remote Sensing in Ecology and Conservation* 10, 360–373. DOI: 10.1002/rse2.377. First published on 4 January 2024; cited as 2023 in the SEA annex. DOI · [Hirschhofer et al.](#)
17. Garvin, J. C., Simonis, J. L. and Taylor, J. L. (2024). Does size matter? Investigation of the effect of wind turbine size on bird and bat mortality. *Biological Conservation* 291, 110474. DOI: 10.1016/j.biocon.2024.110474. North American data on three species; species-specific relationships between rotor size, ground clearance and mortality. [PNNL Tethys · Original article](#)
18. Kumara, H. N. et al. (2022). Responses of birds and mammals to long-established wind farms in India. *Scientific Reports* 12, 1339. DOI: 10.1038/s41598-022-05159-1. Study of collisions, bird communities and habitat use by mammals at Indian wind farms. [Nature · Kumara et al.](#)
19. Brandenburg State Environment Agency, State Bird Conservation Centre. Auswirkungen von Windenergieanlagen auf Vögel und Fledermäuse. Official collision records and technical guidance on recording and assessment. Representative mortality rates require adjustment for search efficiency and carcass losses. [LfU Brandenburg · Bird conservation centre](#)
20. WHO Regional Office for Europe (2018). Environmental Noise Guidelines for the European Region. ISBN 978-92-890-5356-3. Health-related guidelines including wind turbine noise; recommendations with stated strength of evidence. [WHO · Noise Guidelines](#)
21. Marshall, N. S. et al. (2023). The Health Effects of 72 Hours of Simulated Wind Turbine Infrasound: A Double-Blind Randomized Crossover Study in Noise-Sensitive, Healthy Adults. *Environmental Health Perspectives* 131(3), 037012. DOI: 10.1289/EHP10757. Controlled short-term study with 37 participants. [Original article · Marshall et al.](#)
22. Godono, A. et al. (2023). Association between exposure to wind turbines and sleep disorders: A systematic review and meta-analysis. *International Journal of Hygiene and Environmental Health* 254, 114273. DOI: 10.1016/j.ijheh.2023.114273. The authors judge the quality of evidence insufficient for causal conclusions. DOI · [Godono et al.](#)
23. Dastan, M., Bellut-Staack, U., Zhou, J., Scherzinger, B., Bremekamp, M. and Lehmann, C. (2026). Repeated Infrasound Exposure Alters Vasomotion in Mice. *Preprints.org*, Version 1 dated 26 August 2026, manuscript 202608.1927. Experimental mouse study of microvascular responses that has not been peer reviewed. [Preprints.org · Preprint v1](#)
24. Weerappulli Hewage, S. B. W., Wanner, L. and Mauder, M. (2026). Impact of Wind Turbines on Near-Surface Microclimate and Soil Moisture Under Different Stability Regimes. *Boundary-Layer Meteorology* 192, Article 50. DOI: 10.1007/s10546-026-00996-3. Idealised modelling of temperature and soil moisture effects under different atmospheric stability conditions. [Springer · Original article](#)
25. Wang, G., Li, G. and Liu, Z. (2023). Wind farms dry surface soil in temporal and spatial variation. *Science of the Total Environment* 857, 159293. DOI: 10.1016/j.scitotenv.2022.159293. Site-specific study in China; summary in the PNNL Tethys archive. [PNNL Tethys · Wang et al.](#)

26. Liu, P. and Barlow, C. Y. (2017). Wind turbine blade waste in 2050. *Waste Management* 62, 229–240. DOI: 10.1016/j.wasman.2017.02.007. Projection of cumulative global rotor blade waste; original manuscript in the University of Cambridge repository. [Cambridge](#) · [Liu and Barlow](#)
27. Moradi, R. and Yang, L. (2026). Energy, Economic, and Environmental Assessment of Wind Turbine Blade Thermal Recycling Coupled with Organic Rankine Cycle Heat Recovery and Power Generation. *Sustainability* 18(12), 5859. DOI: 10.3390/su18125859. Pilot-validated model and scaling simulation; published on 8 June 2026. [University of Strathclyde](#) · [Original article](#)
28. European Chemicals Agency (ECHA) (2025/2026). ECHA update on the per- and polyfluoroalkyl substances (PFAS) restriction process, 27 August 2025, particularly p. 1 and footnote 2 on the energy sector; additionally ECHA, Per- and polyfluoroalkyl substances (PFAS), on persistence, environmental spread and remediation requirements. Accessed 30 September 2026. [ECHA](#) · [PFAS restriction process](#) · [ECHA substance risks](#)
29. Gibbons, S. (2015). Gone with the wind: Valuing the visual impacts of wind turbines through house prices. *Journal of Environmental Economics and Management* 72, 177–196. DOI: 10.1016/j.jeem.2015.04.006. Quasi-experimental property analysis for England and Wales; original working paper at the LSE. [LSE](#) · [Original working paper](#)
30. Liechtensteinische Kraftwerke. Unsere Stromzukunft. Presentation of procurement and generation options and the company's assessments of hydrokinetic power buoys in the Rhine; refers to variable river flows and high suspended sediment and bedload levels. Accessed 30 September 2026. [LKW](#) · [Our electricity future](#)
31. Fields, J., Oteri, F., Preus, R. and Baring-Gould, I. (2016). Deployment of Wind Turbines in the Built Environment: Risks, Lessons, and Recommended Practices. NREL/TP-5000-65622, June 2016. DOI: 10.2172/1260340. Research report with case studies, site requirements and recommendations for wind energy on buildings. [NREL](#) · [Original report](#)
32. U.S. Department of Energy. Frequently Asked Questions on Small Distributed Wind Systems, particularly Can I put a wind turbine on my roof? Technical guidance on turbulence, vibration transmission, noise and the lower economic viability of typical rooftop installations. Accessed 30 September 2026. [U.S. DOE](#) · [Small wind turbines](#)
33. Government of the Principality of Liechtenstein (2023). Klimastrategie Liechtenstein 2050. Energy – Buildings and Industry section: identifies Samina's conversion into a pumped storage power plant in 2015. Primary evidence of existing pumped storage infrastructure. [Government](#) · [Climate strategy 2050](#)