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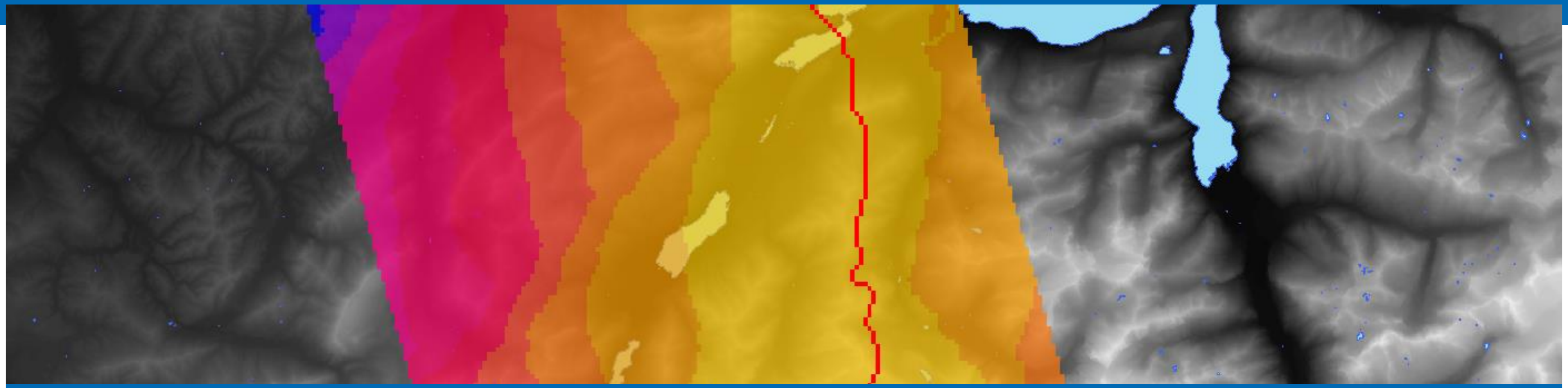

How To Optimize Transmission Line Paths and Corridors with Geographic Information Systems and Multi-Criterial Decision Analysis

26.09.2016, Klagenfurt

Research in Progress Presentation at the PhD Workshop “Energy Informatics”

Joram Schito

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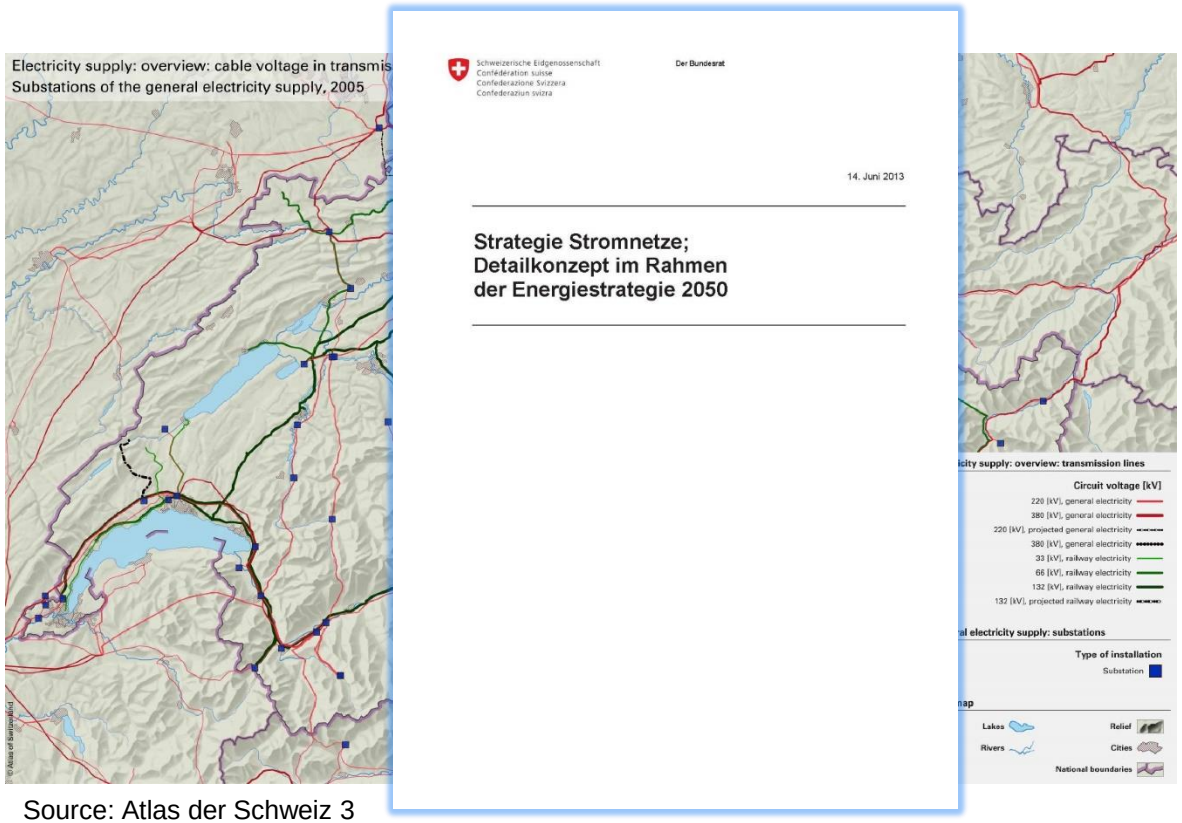
Agenda

1. Project Background
2. Procedure and MCDA Concept
3. Current Results
4. Future Outlook
5. Demonstration
6. Discussion

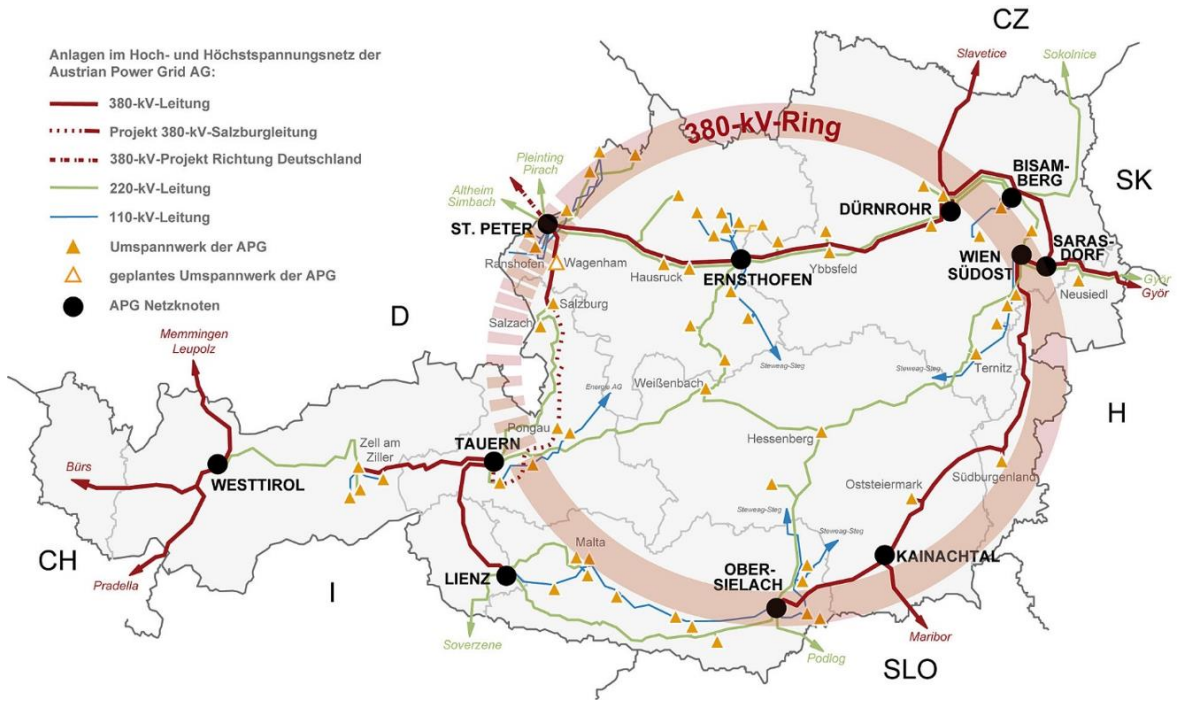
Project Background

Problem, context, and goals

Problem: The power grid must be extended



Source: Atlas der Schweiz 3

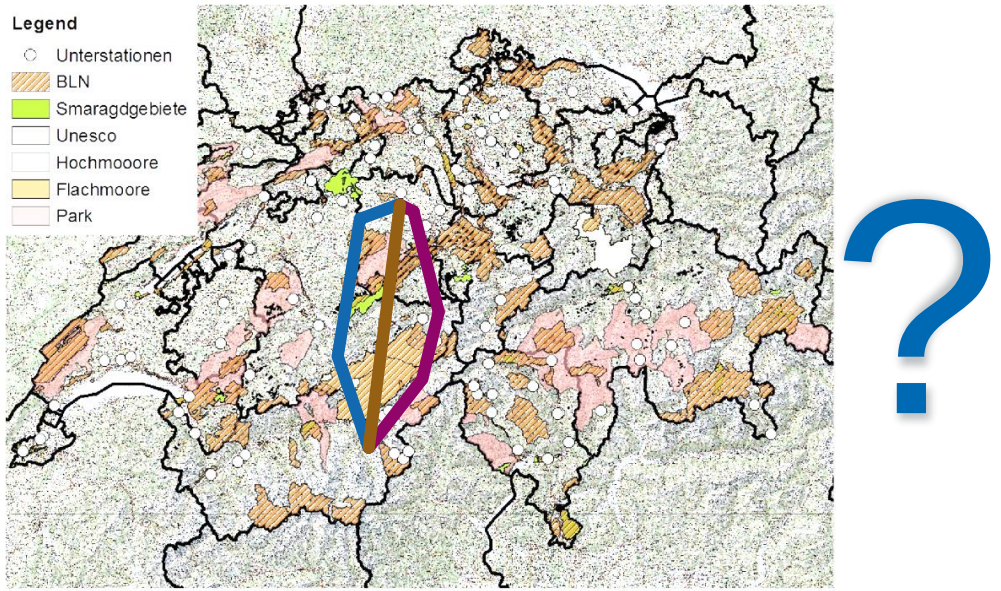


Source: APG

Problem: The power grid must be extended and new paths must be found because the laws changed since the existing grid was built

- How can the best path be found?
- How can current legal specifications be considered?
  - e.g. minimum distances to buildings
- What defines the best path? Who defines this?
- Who is involved in the decision process? How will different opinions/solutions be considered?
- **Where should the future power line be built: Here, there, or there?**

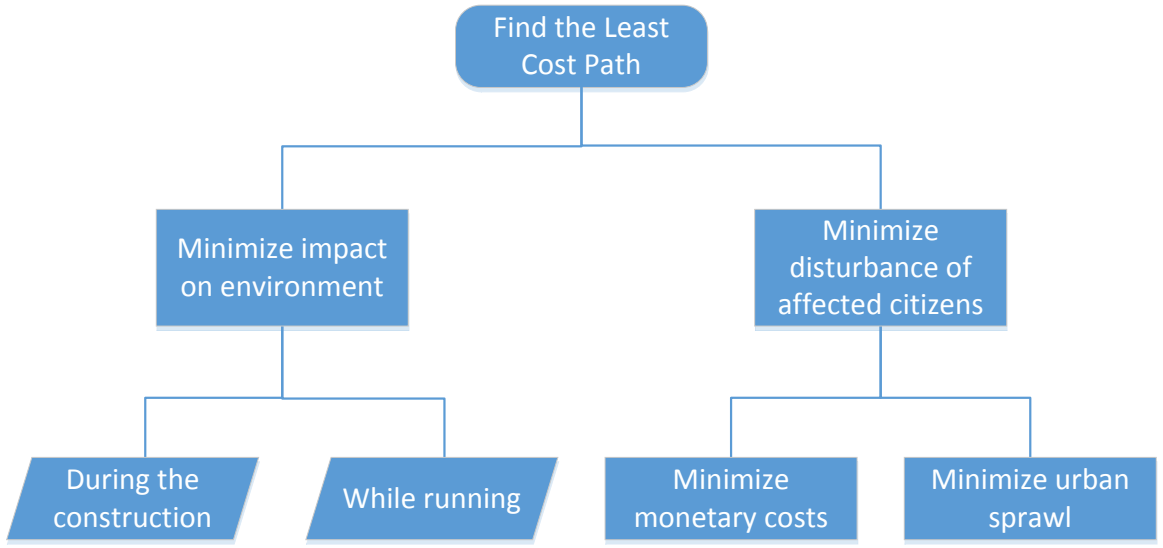
- Decision Problem: Solved by **Multi-Criteria Decision Analysis (MCDA)**
- Spatial Problem: Solved by aver **Geographic Information System (GIS)**



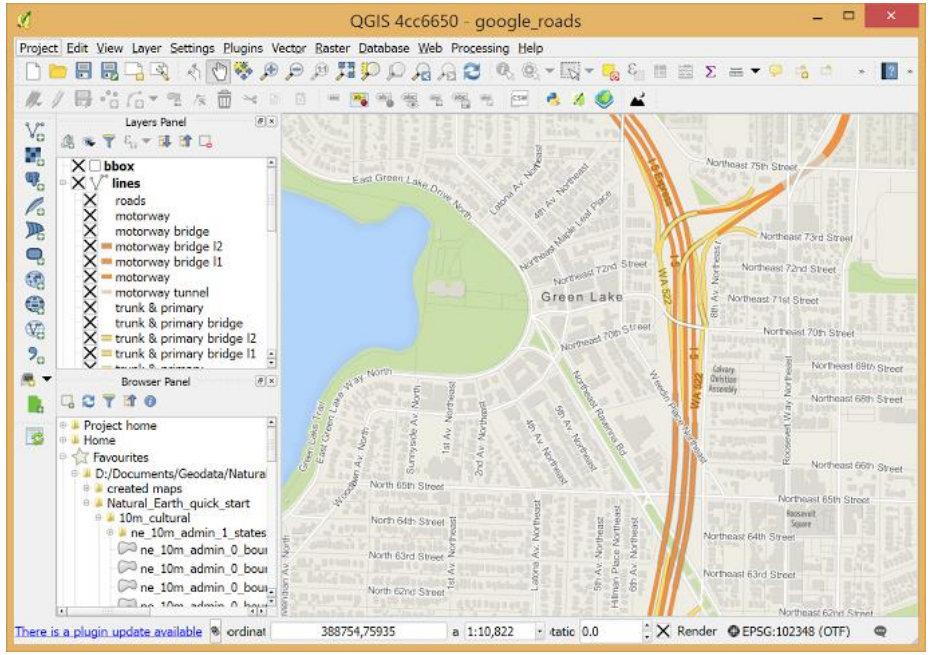
Source: Master Thesis Zoran Brankovic (2013)

What are Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS)?

- **MCDA** is a set of strategies that allow decision-makers to find the optimal solution within a set of different criteria, and thus, of different alternatives.



- **GIS** is a software that allows modeling, administration, processing, analysis, and presentation of spatial data.



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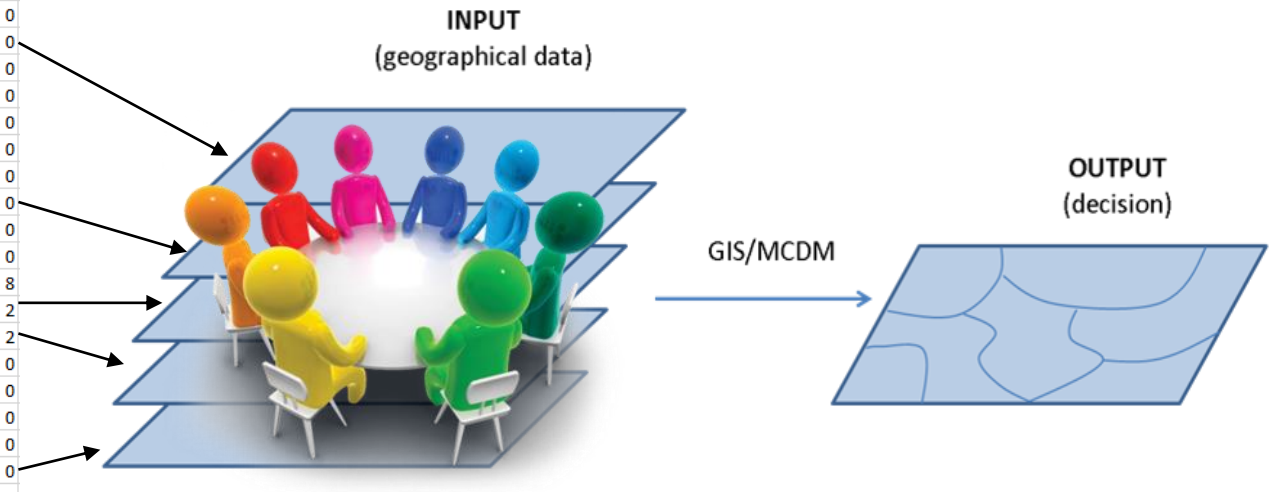
MCDA combined with GIS: Data model, decision model, and weighting define the outcome

D	E	F	G
OBJCODE	OBJNAME	Resistance_OH	Resistance_CAB
jg	Oberkreide	2	2
jh	Unterkreide	2	2
ji	Malm	0	0
jj	Bathonien - Oxfordien	0	0
jk	Trias - Dogger	0	0
jl	Dogger	0	0
jm	Lias	0	0
jn	Trias	0	0
jo	Perm (Verrucano)	0	0
jp	Oberkarbon (- Unterperm)	0	0
jq	Devon - Unterkarbon	0	0
A	Gebiete ohne ergiebige Grundwasservorkommen	0	0
B	Gletscher, Firn	7	8
C	Grundwasservorkommen in verkarstungsfaehigen Festgesteinen	2	2
D	Oberflaechengewaesser	2	2
E	Sehr ergiebige Grundwasservorkommen in den Talsohlen	0	0
F	Ergiebige Grundwasservorkommen z.T. ausserhalb von Talsohlen	0	0
G	Weniger ergiebige Grundwasservorkommen	0	0
H	Weniger ergiebige Grundwasservorkommen in gekluefteten und poroesen, nicht verkarstu	0	0
I	unbestimmt	0	0
71	Erhoehter Sulfatgehalt (Gips- und Anhydritloesung, >100 mg/l)	0	0
72	Erhoehter Chloridgehalt (Steinsalzloesung, >50 mg/l)	0	0
74	Verminderte Sauerstoffsaettigung (z.B. Torfbedeckung, <20 %)	0	0



This is our product: a Decision Support System (DSS) in which a power grid can be planned in 3D and allows

Interaction

Communication

Data Integration

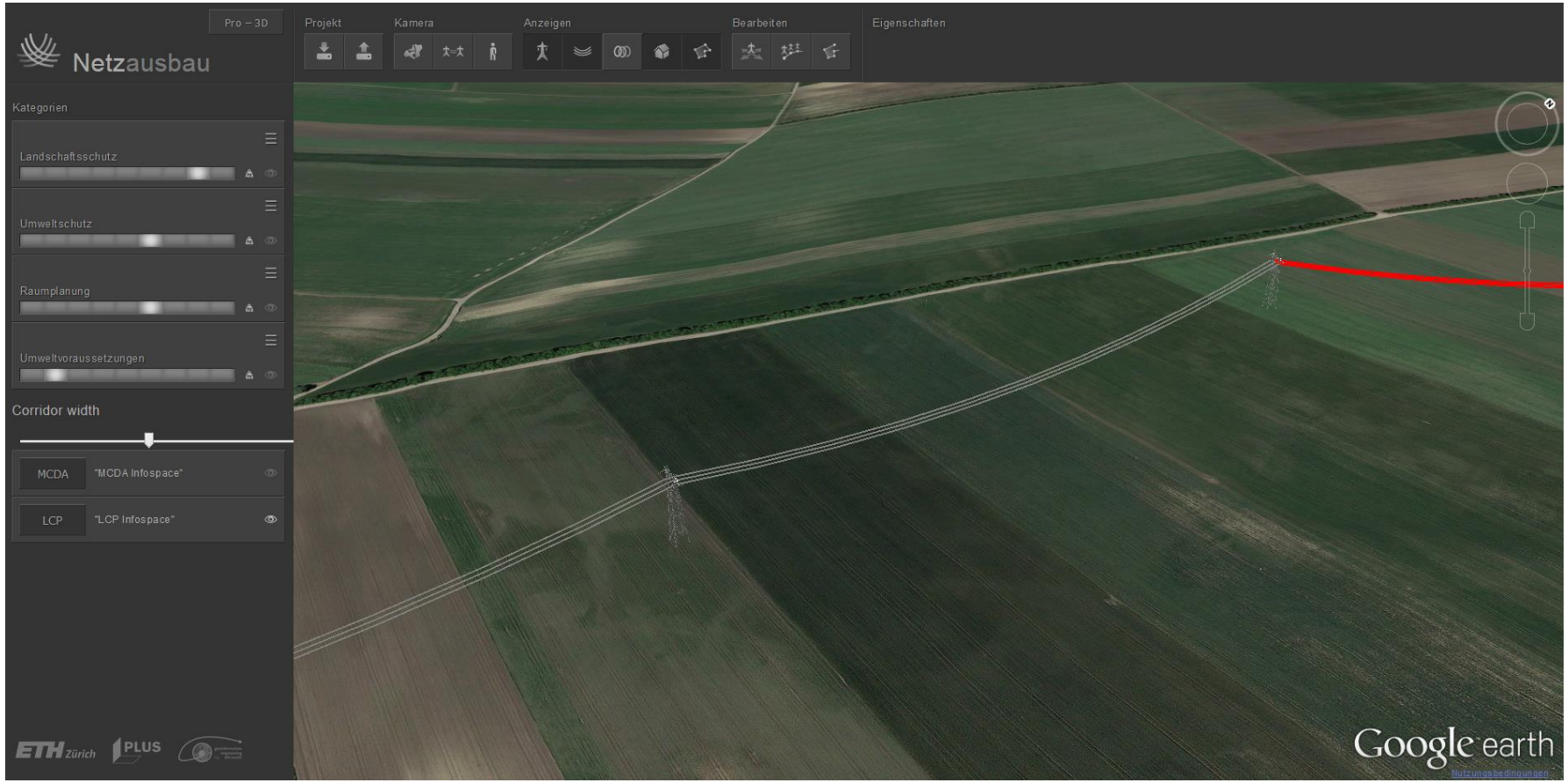
Realistic Impressions

LiDAR Data Integration

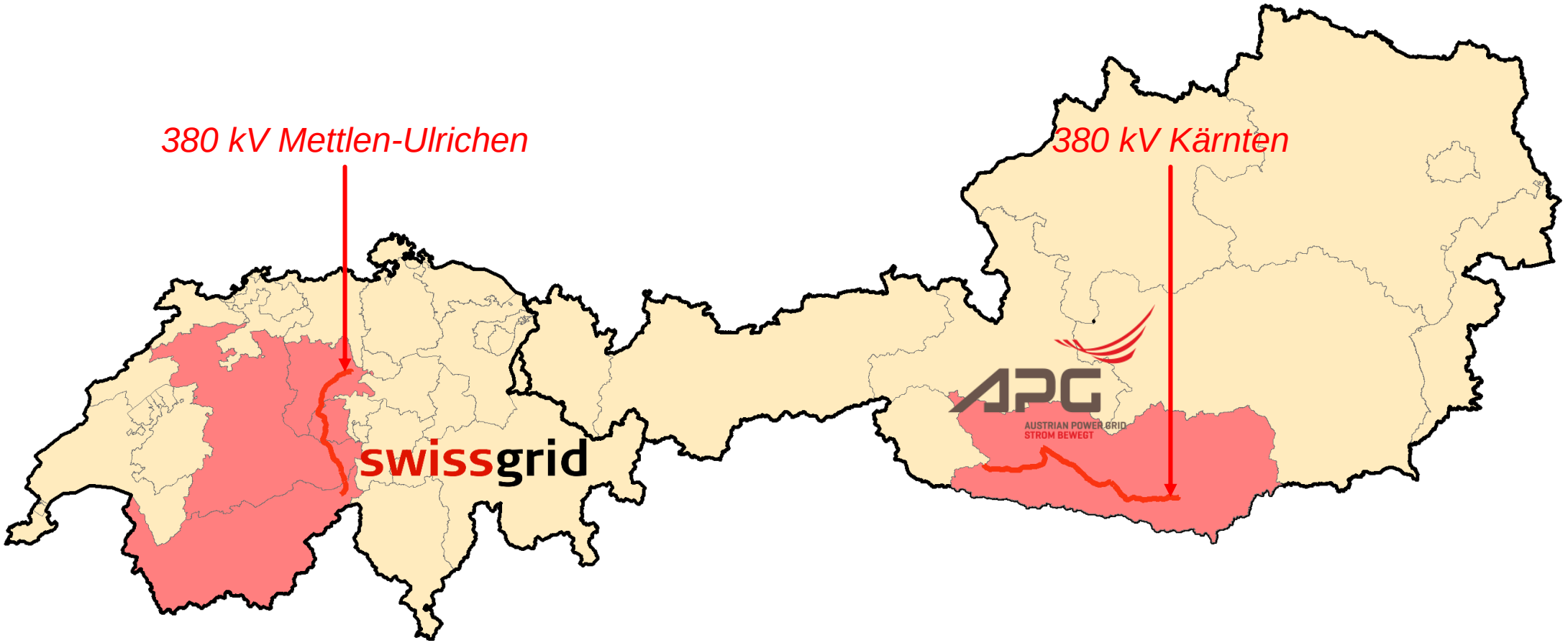
Exchange of Ideas

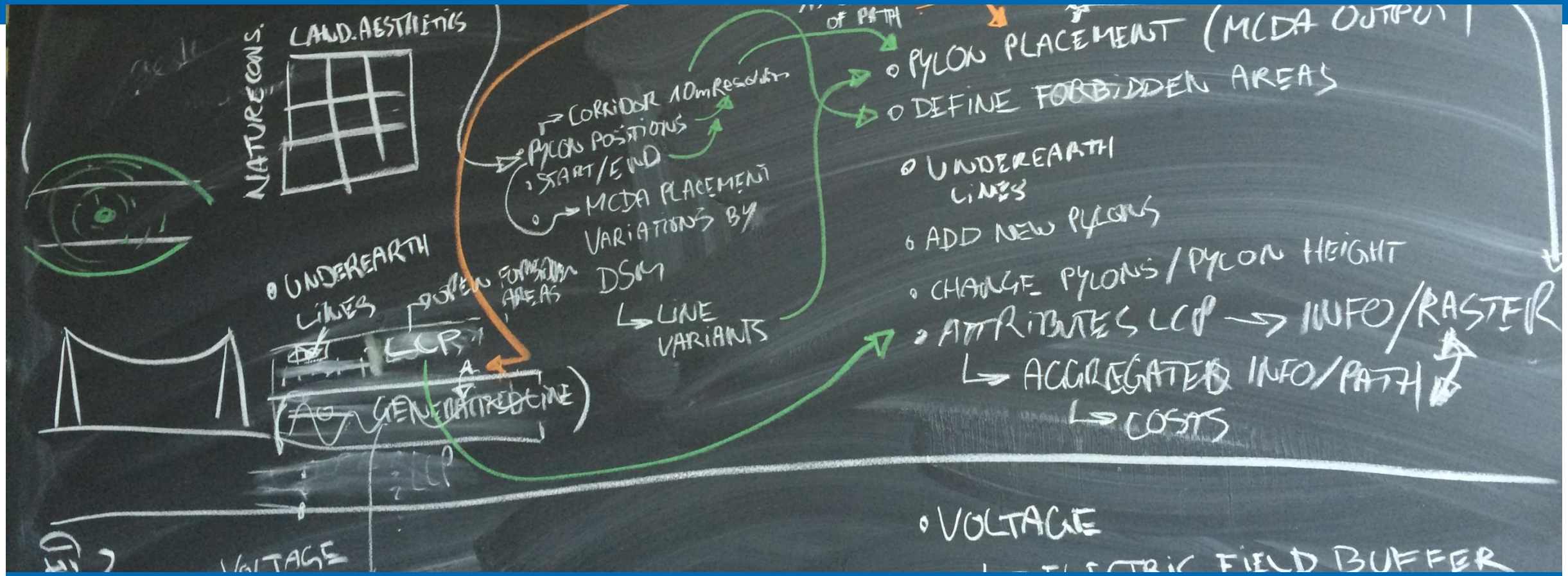
Weighting

Cost Estimation



Our study area: We focus on the grid 380 kV expansion in Switzerland and Austria





Concept

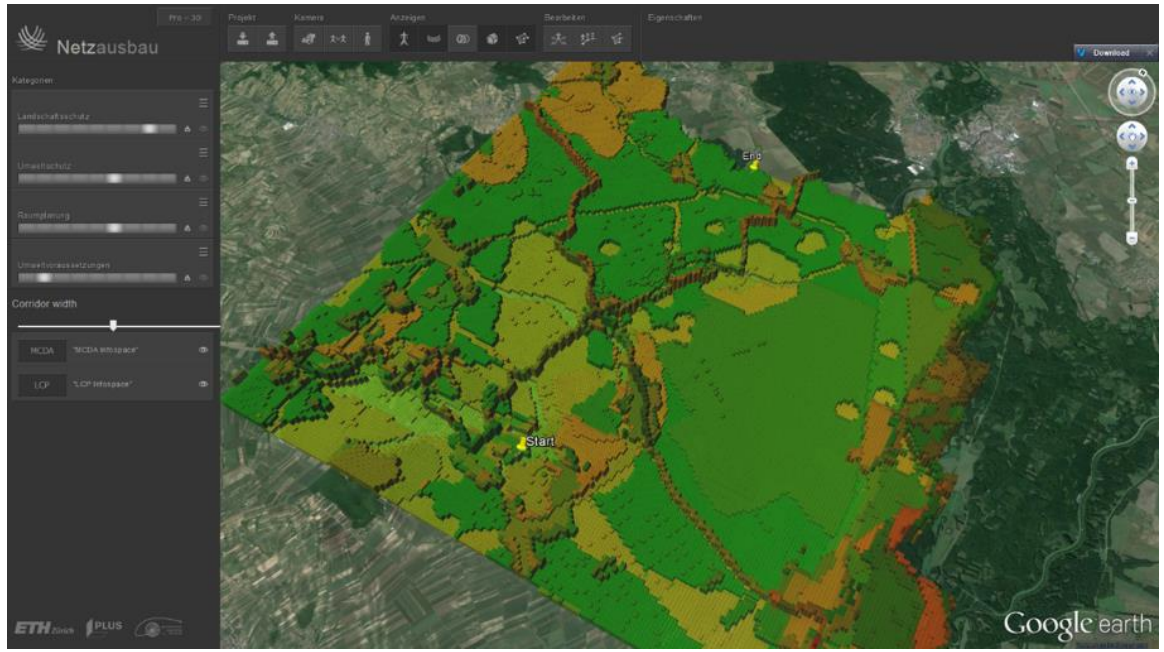
Introduction to the goals, the context, and the problems

Input, transfer, and output

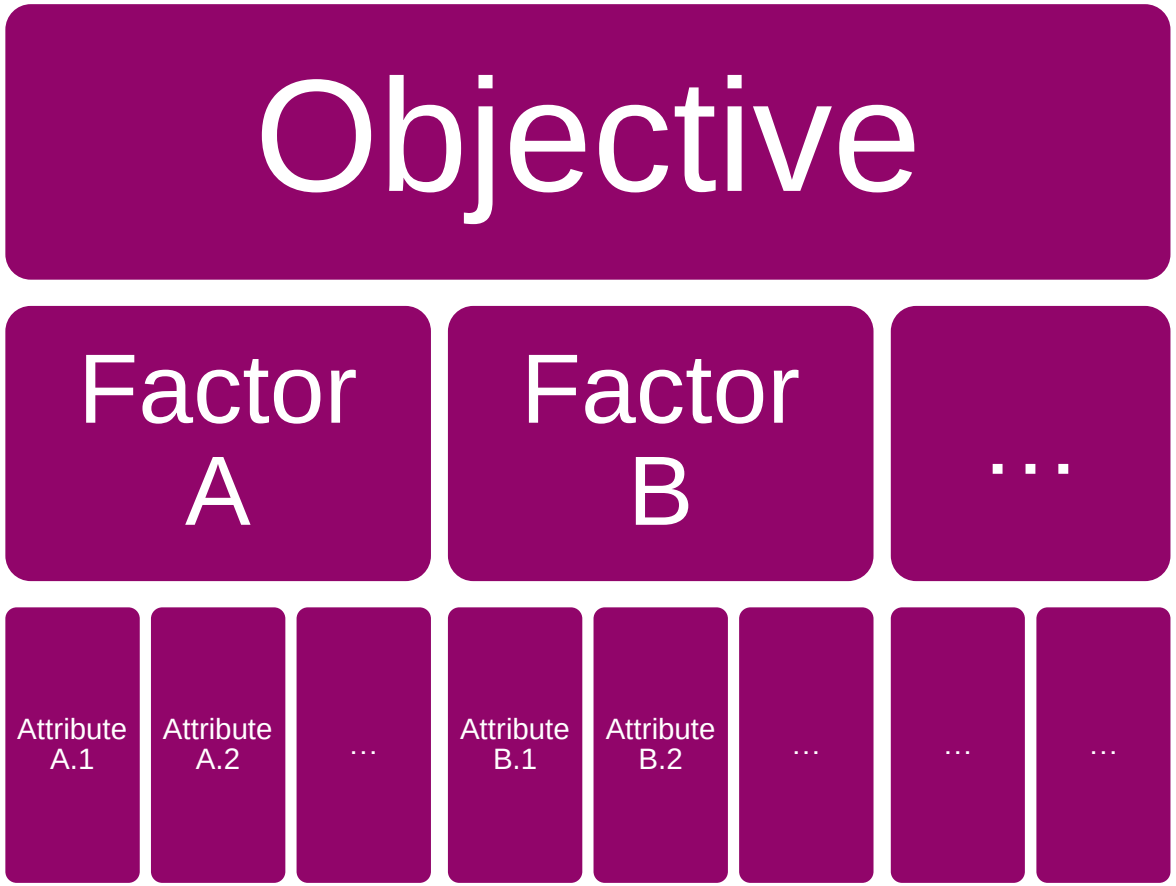
Define data, start, end, constraining points, voltage, and weights

Computation of *cost surface, least cost corridor,* and *least cost path*

Visualize the result in 3D, including monetary and ecosystem costs



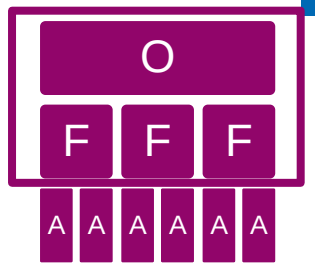
How the MCDA model is built



1. Define an objective
2. Define factors relevant to achieve the objective
3. Define measurable attributes for each factor that state its goodness of achievement

- One set of attribute weights = one alternative
- Every possible attribute weight combination = Every possible alternative
- **STOP!!** A few alternatives are sufficient for comparison

The main objective determines five factors to consider



High-level objective

- Find the least cost path for a new power line according to the set weights

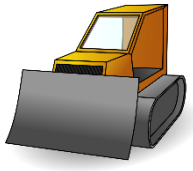
Technical and Natural Constraints

Landscape

Factors to consider

- Technical and natural constraints
- Impact on landscape
- Impact on environment
- Impact on the citizens' perception
- Costs

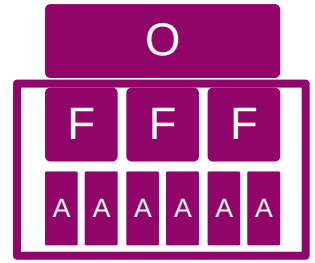
Costs in Terms of Money and Ecosystem Impact



Environment

Citizens

From each factor, measureable attributes are derived



Factor to consider

- Technical and natural constraints

Operationalize the attributes

- Slope / relief / sag
- Distance between transmission towers
- Geology, pedology
- Natural hazards

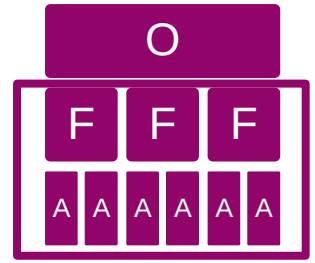
Factor to consider

- Impact on landscape

Operationalize the attributes

- Landscape conservation laws
- Affected land by considering its vulnerability
- Especially wetlands, dry grasslands, geotopes

From each factor, measureable attributes are derived



Factor to consider

- Impact on environment

Operationalize the attributes

- Animal protection regulations
- Animal habitats
- Special: Bird protection
- Vulnerable ecosystems
- Quiet zones

Factor to consider

- Impact on the citizens' perception

Operationalize the attributes

- Distance to settlements
- Distance to roads
- Counteract urban sprawl by bundling with linear infrastructure
- Visibility

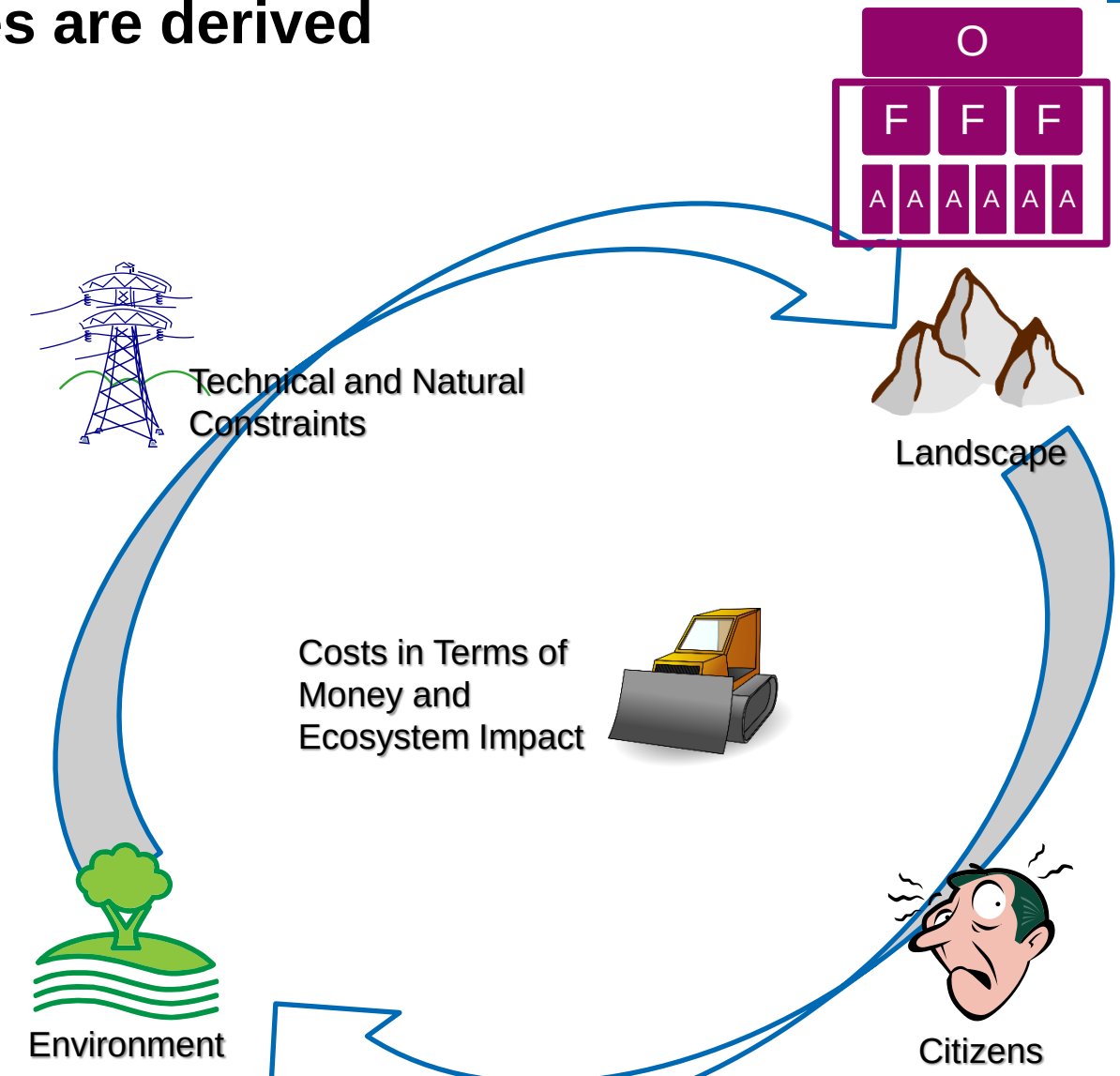
From each factor, measureable attributes are derived

Factor to consider

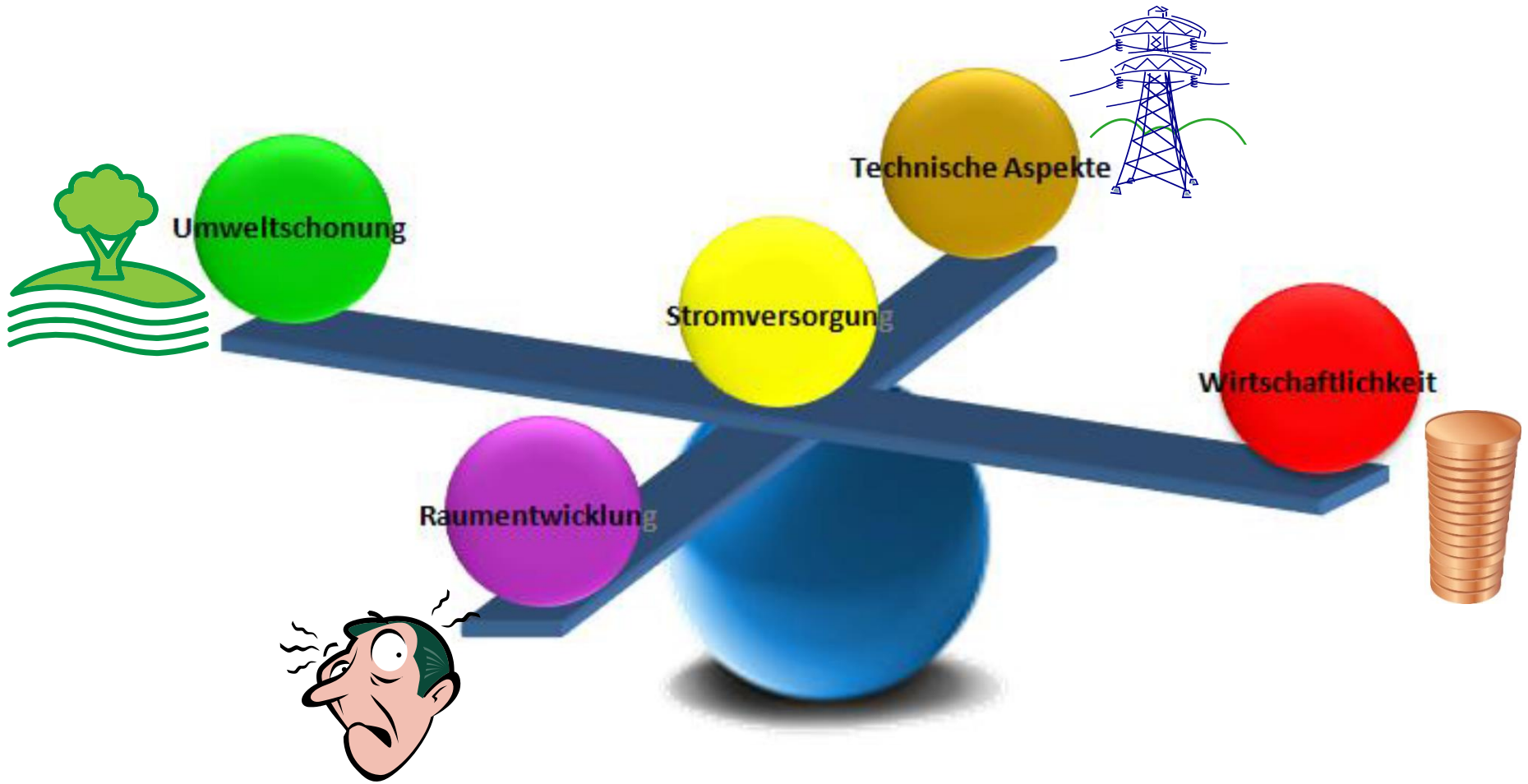
- Costs

Operationalize the attributes

- Effective monetary costs for access and construction
- Affected land by considering its vulnerability
- Impact on environment and landscape



All factors must be balanced by law



«Bewertungsschema für Übertragungsleitungen», BFE (2013)

Five factors are considered in the MCDA

Technical and Natural Constraints

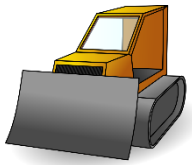
Impact on

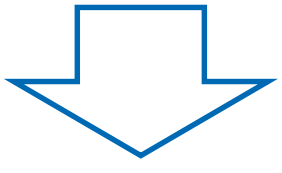
Landscape

Environment

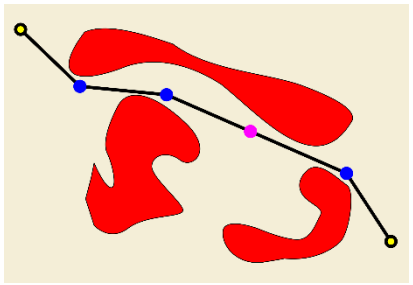
Citizens

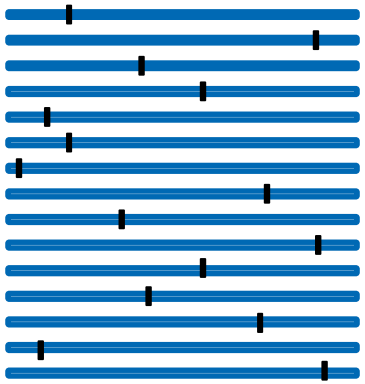
Costs in Terms of Money and Ecosystem Impact





Restricted Areas
Constraint Values





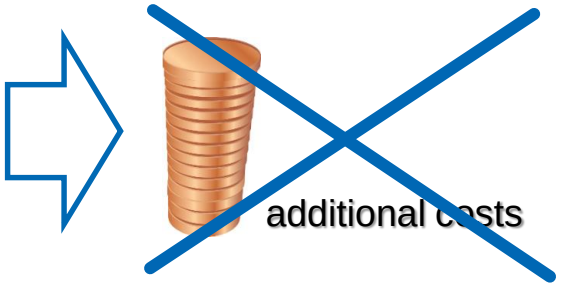
Independent Variables

Dependent Variables

$f(x) = \ldots$

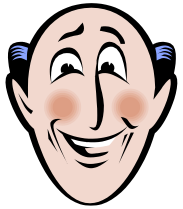
Goal: Develop a communication platform for all stakeholders to reduce the objections

citizens can use right of veto to impede a project



additional costs

instead



foster transparency

integrate the citizens in the planning process

allow communication between the stakeholders

The 3D DSS…

- **saves time**
- **increases citizens' acceptance**
- **offers realistic visualizations in 3D**
- **counteracts the urban sprawl**

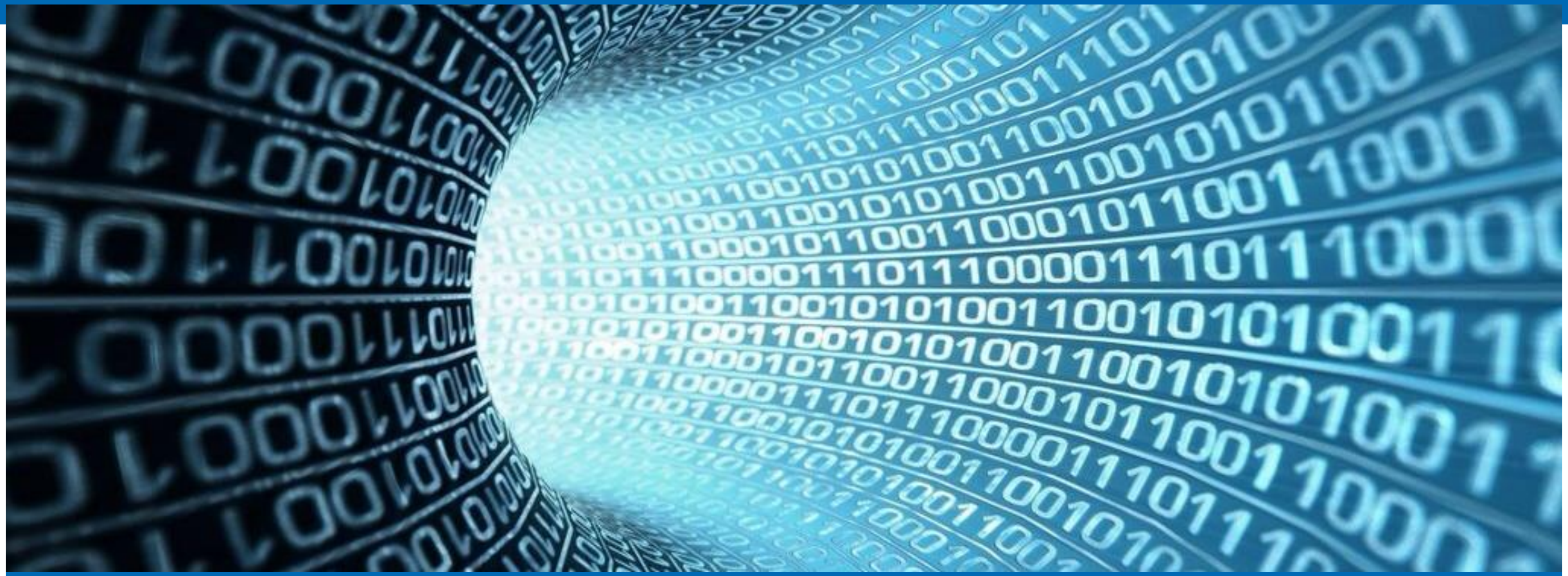
Procedure: Project work packages over 3 years

WP1
- Examine needs, collect data and create a geodatabase structure

WP2
- Develop an algorithm for routing, transmission tower positioning, and cost estimation

WP3
- Develop a web-based, collaborative 3D DSS, and integrate the algorithm of WP2

WP4
- Conduct interviews with stakeholders and evaluate case studies



Data Mining

Results of Workpackage 1

Data Mining = Workpackage 1

WP1

- Examine needs, collect data and create a geodatabase structure

WP2

WP3

WP4

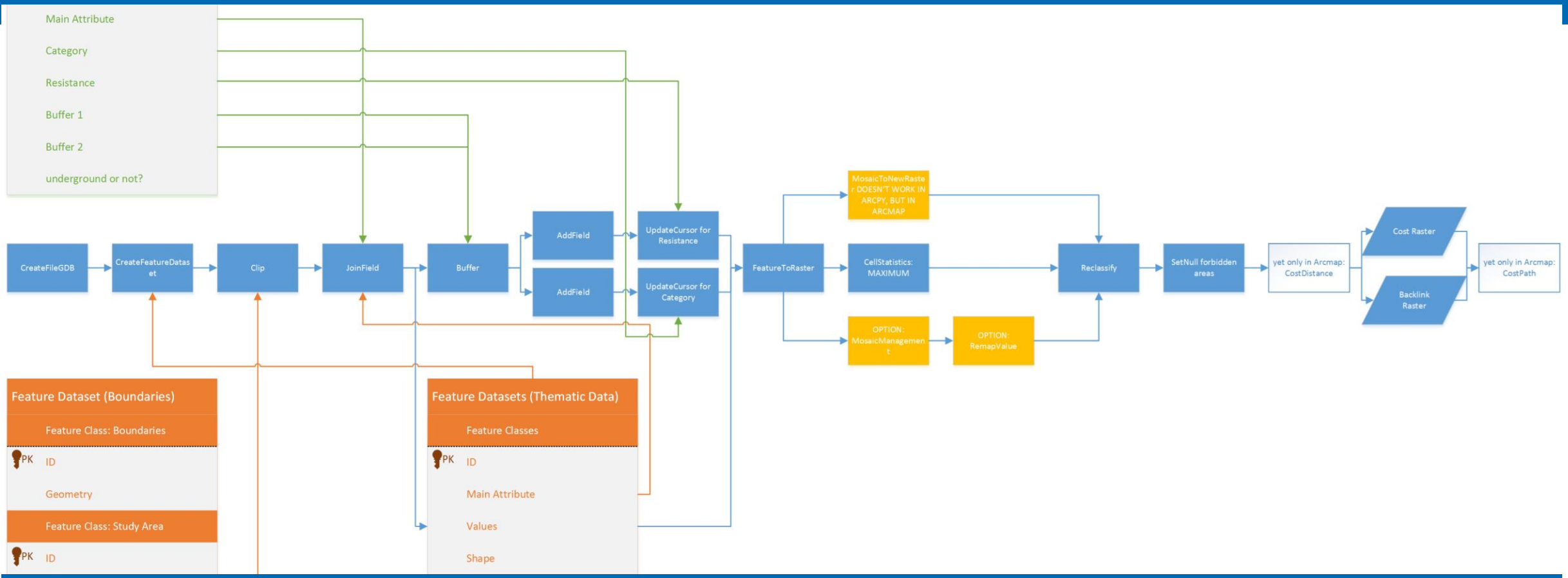
- Steps
  - Create a data handling concept
  - Collect, analyze, and standardize data
  - Create a guideline

Result: Definition of a model to preprocess and to structure data using 4 factors and 15 subfactors

Factor	Subfactors
Environment protection	Ecosystems supporting biodiversity Protective habitats Waters protected by water act
Landscape conservation	Landscapes protected by law Conservation of agricultural land Natural monuments Visibility of power line Anti-sprawl by linear infrastructure
Urban planning	Urban areas Recreational and tourism areas Areas of high cultural value Visibility
Natural constraints	Natural hazards Slope Building ground

Factor	Subfactors
Costs	Monetary costs Impact on environment Impact on landscape

Which alternative will the stakeholders choose?



Algorithm Development

Results of Workpackage 2

Algorithm Development = Workpackage 2

WP1

WP2

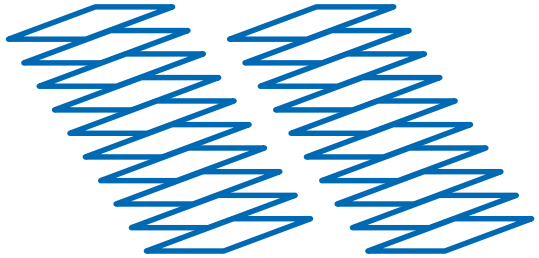
- Develop an algorithm for routing, transmission tower positioning, and cost estimation

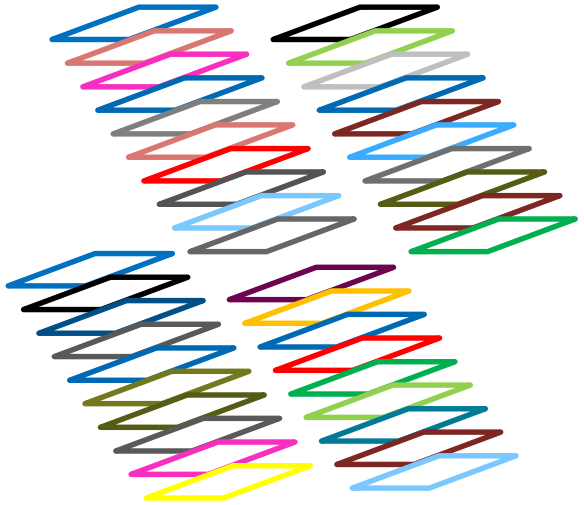
WP3

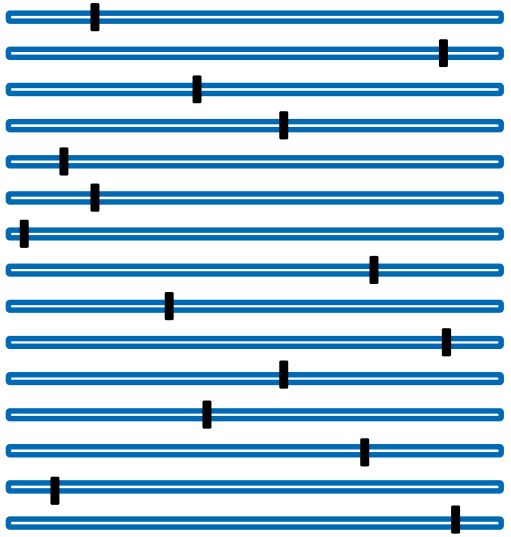
WP4

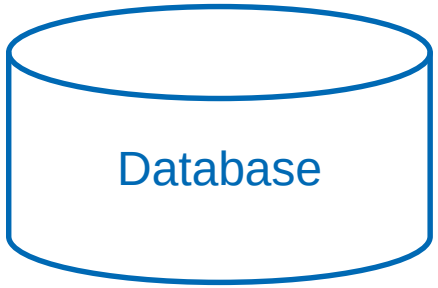
- Steps
  - Develop a weighting method using MCDA
  - Develop optimization methods

This is how the MCDA works: First, preprocess the data





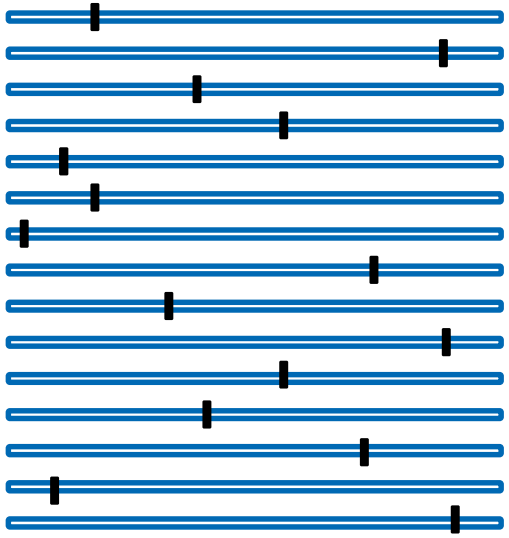




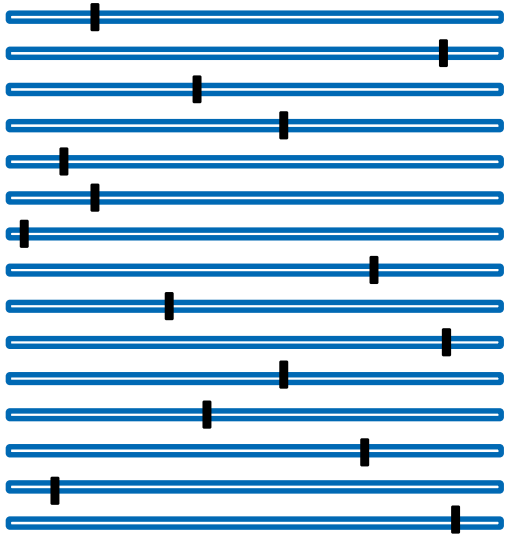
1. Take the files and split them based on their main attribute.
2. Reduce them to 15 subfactors and store them in a database.

This is how the MCDA works: Next, the factors and subfactors are weighted

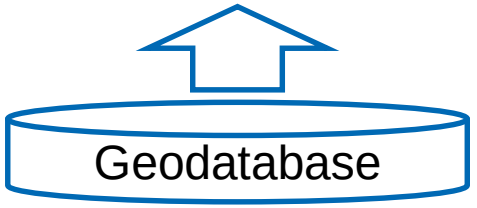
4 factors to weight

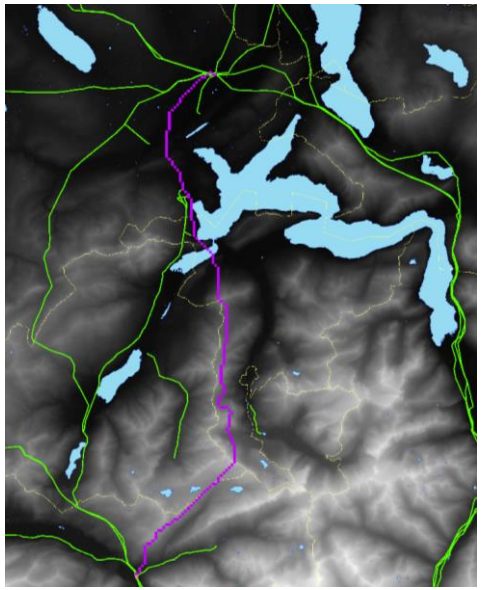


15 subfactors to weight



define the subfactor's resistance





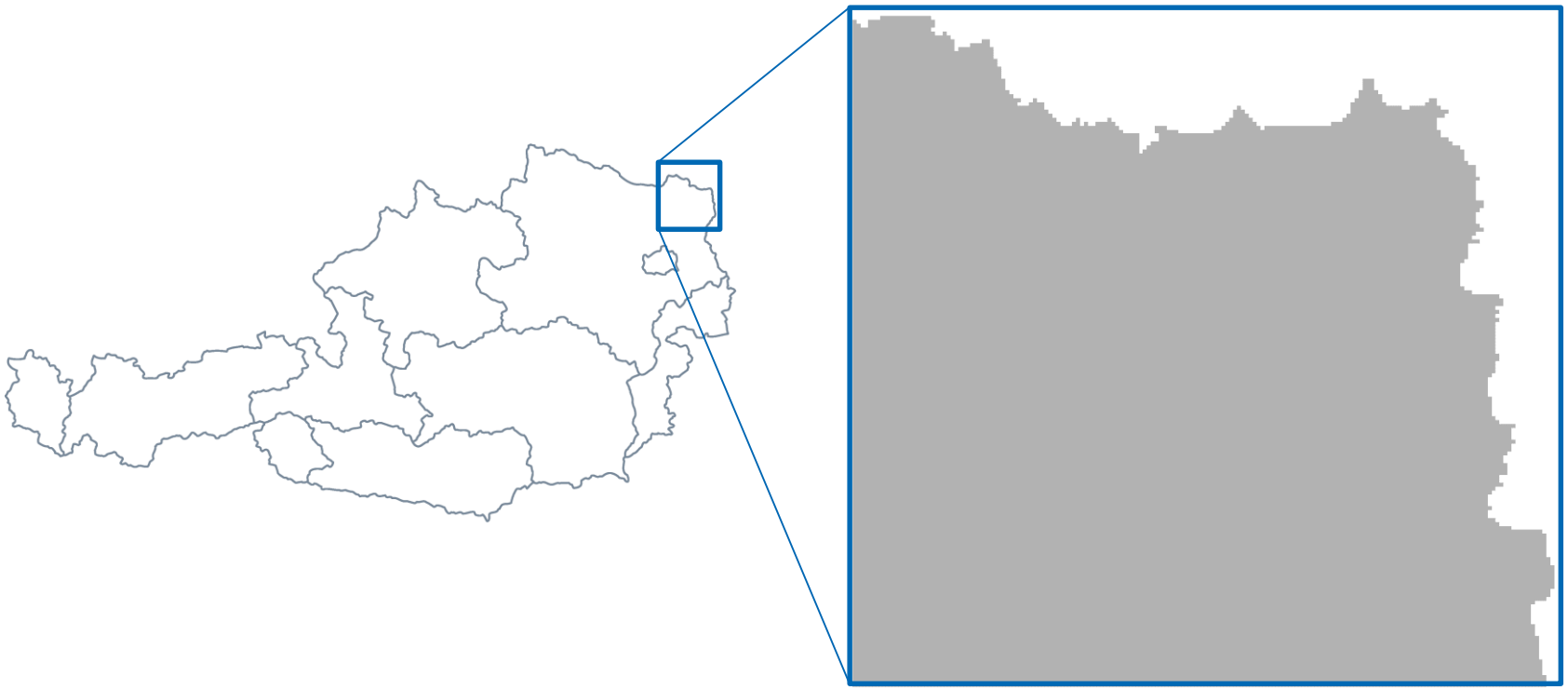
1 output

a few minutes

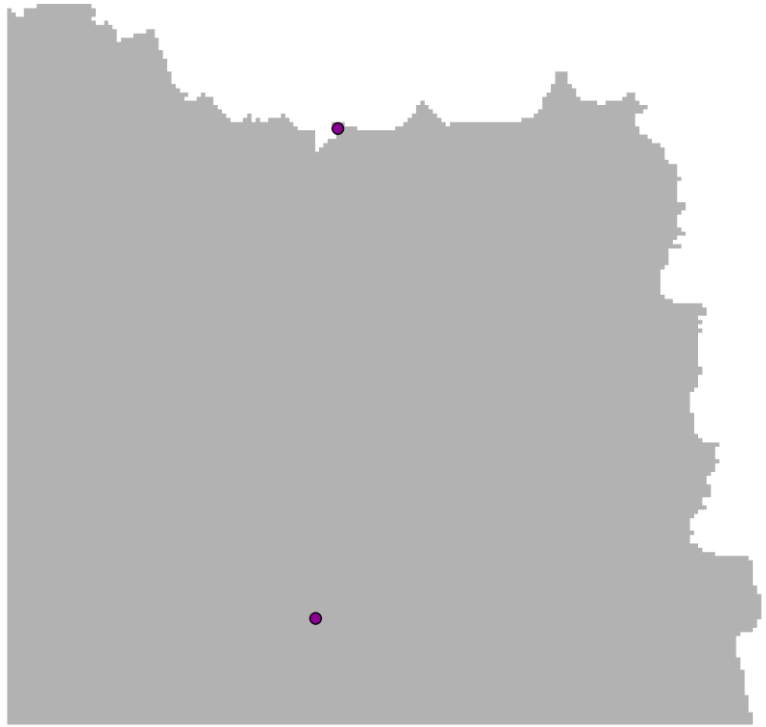
How the Least Cost Corridor and the Least Cost Path are computed

Introduction to the precondition, to the theoretical framework and to the procedure

How a cost surface is built



How a cost surface is built



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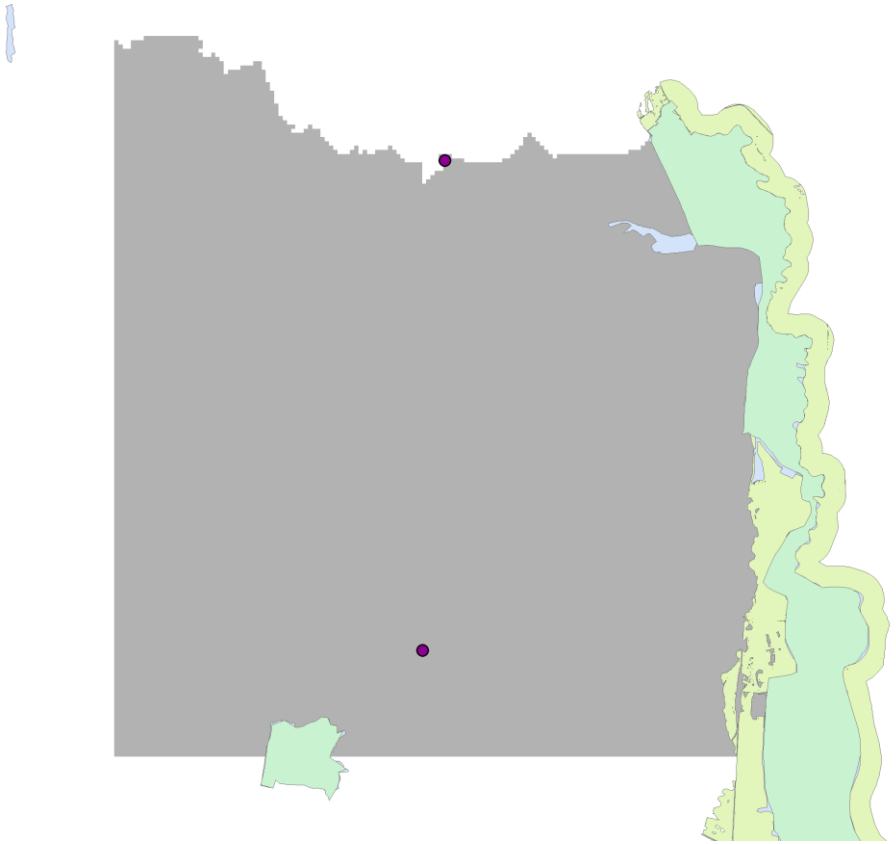

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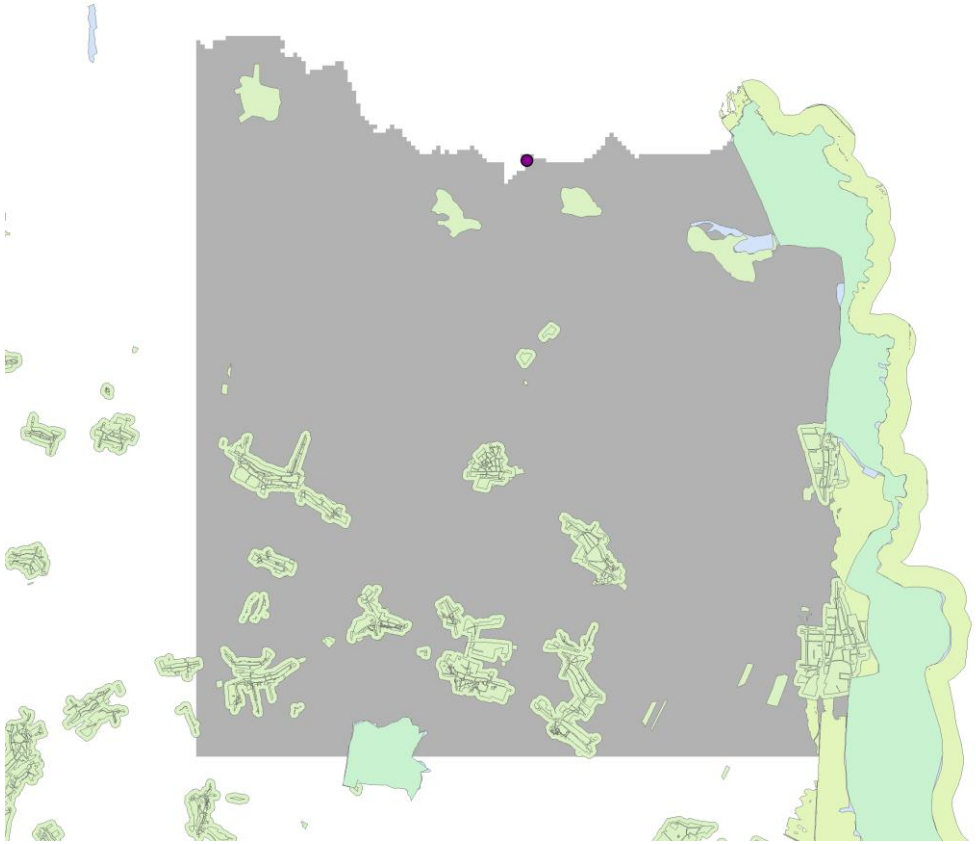

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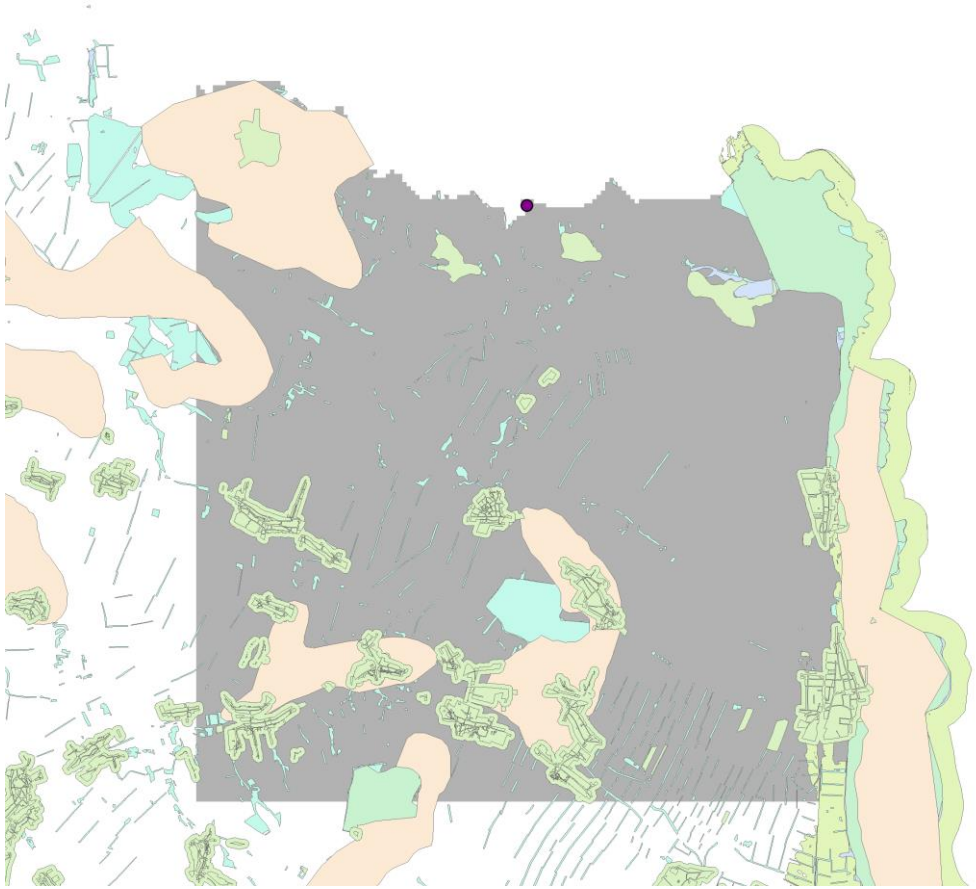

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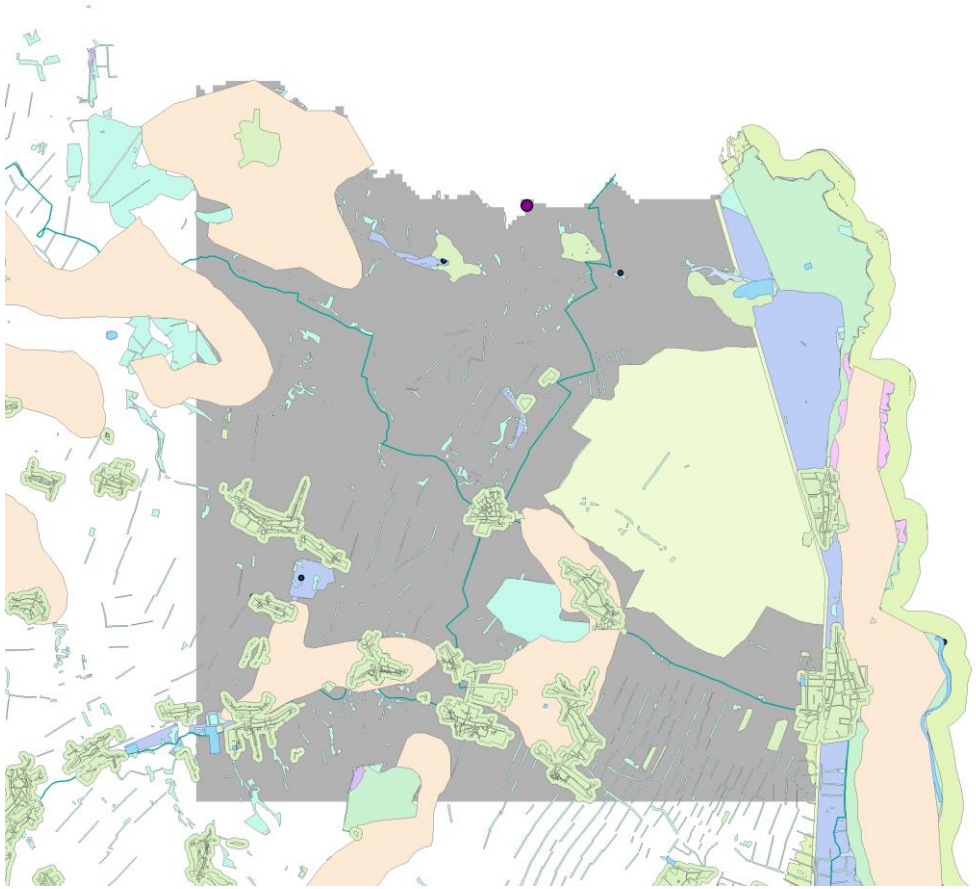

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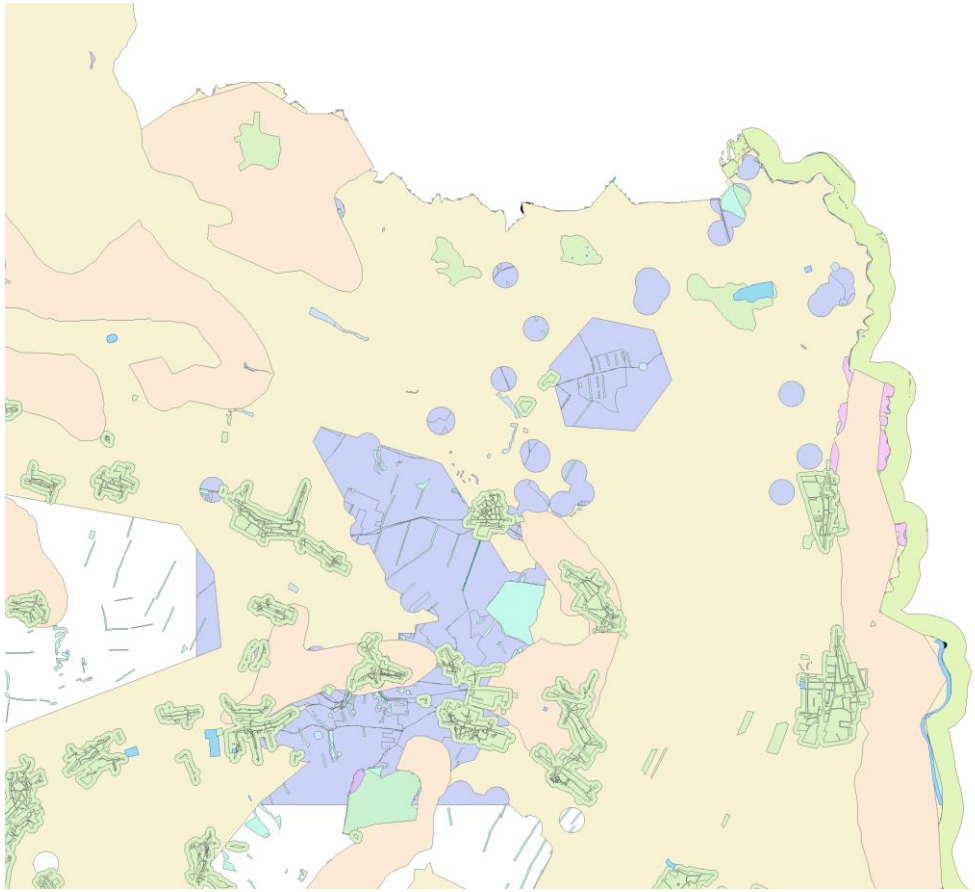
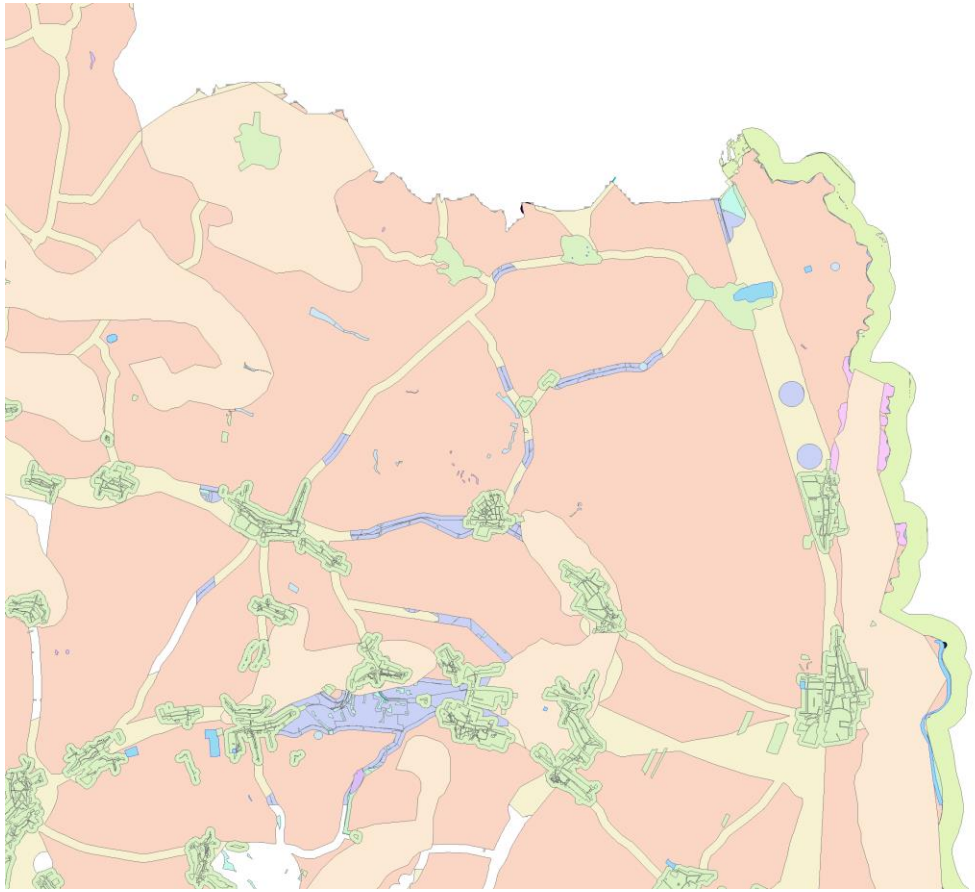
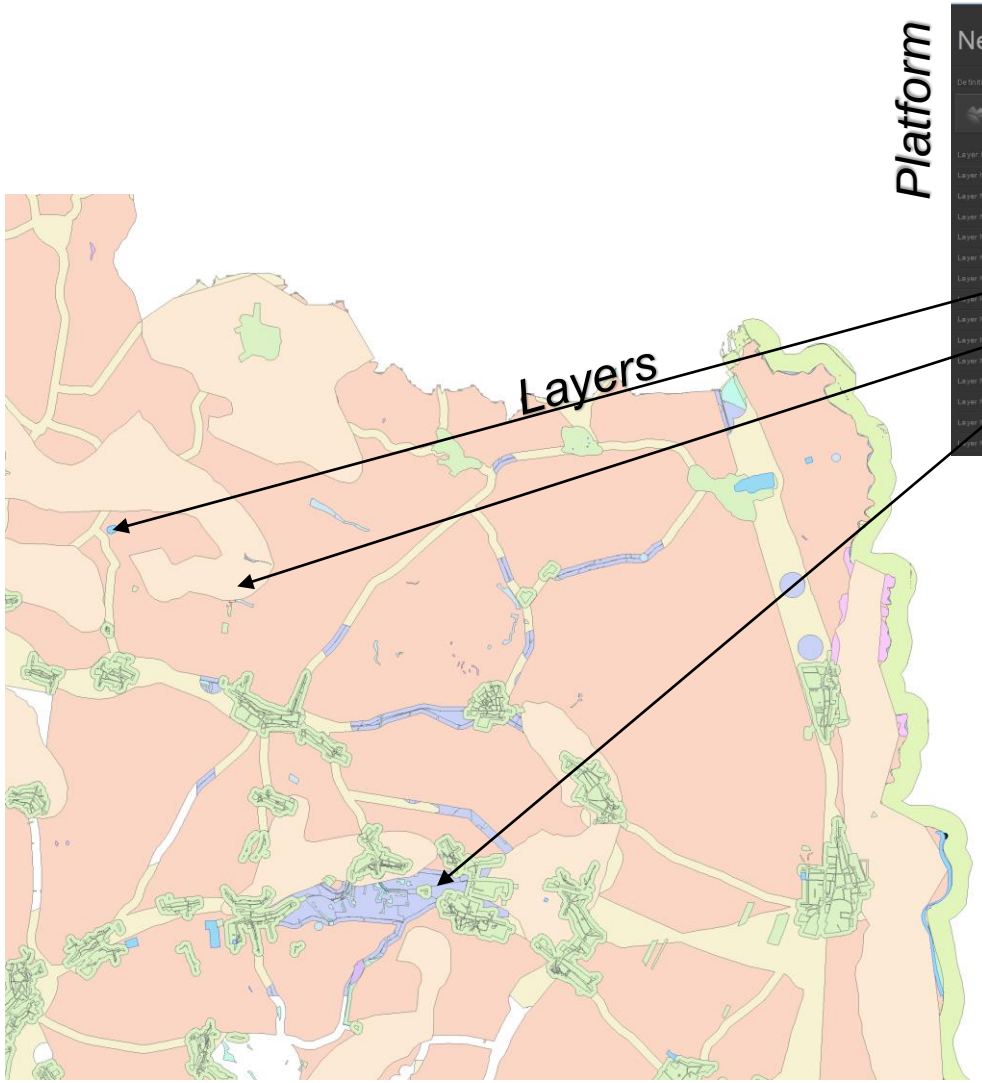
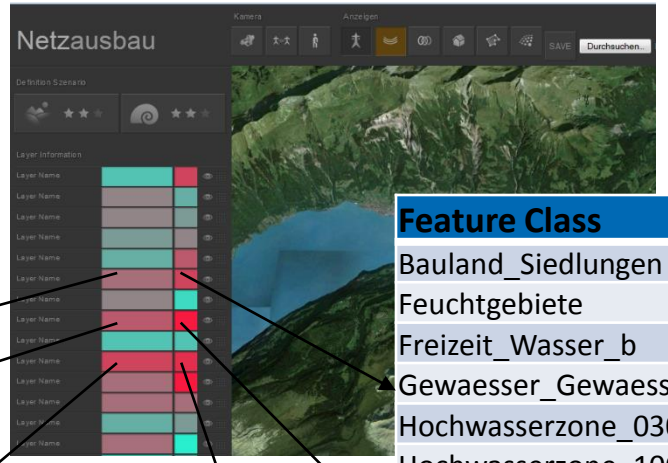


How a cost surface is built



How a cost surface is built



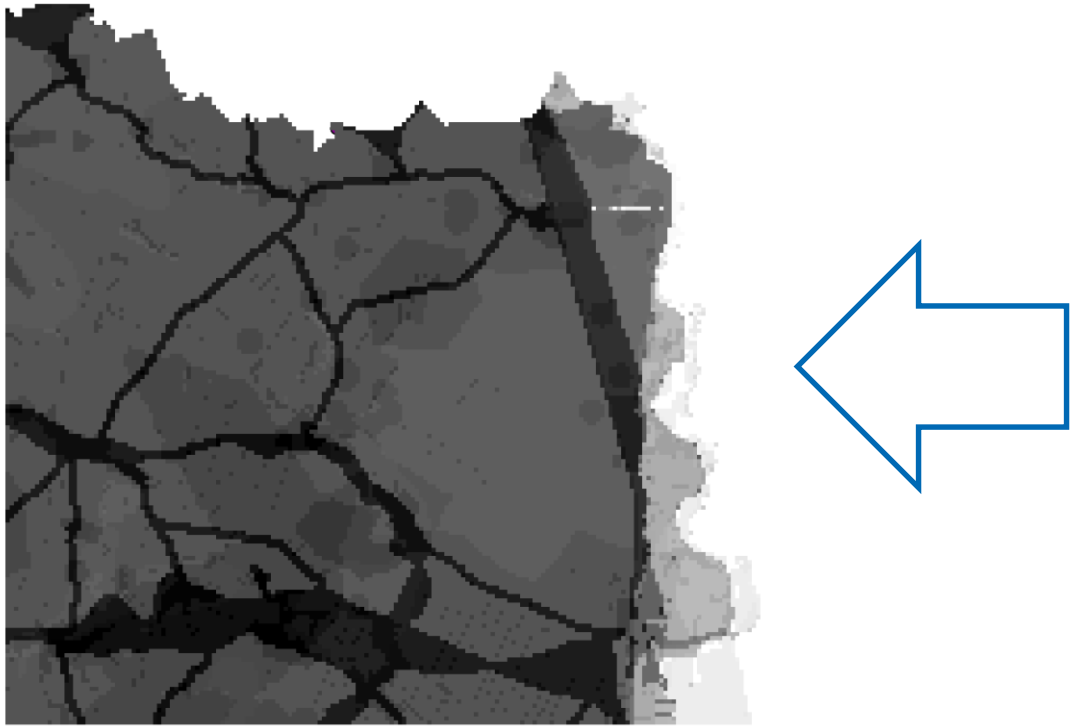


Weights

Weight Table

Feature Class	Resistance	Feature Weight
Bauland_Siedlungen	9	0.06
Feuchtgebiete	7	0.2
Freizeit_Wasser_b	8	0.22
Gewaesser_Gewaesserschutz	7	0.05
Hochwasserzone_030a	2	0.41
Hochwasserzone_100a	2	0.31
Hochwasserzone_300a	5	0.28
Kulturlandschaften_2	4	0.12
Landwirtschaftliche_Nutzflaechen	5	0.2
Naturdenkmaeler	2	0.25
Oekosysteme	7	0.17
Radrouten_b	5	0.72
RNA_Landschaftsschutzgebiet	5	0.05
RNA_Naturschutzgebiet	0	0.08
Sprawl_EnergieInfrastruktur	5	0.15
Sprawl_lineareInfrastruktur	9	0.35
Trockenrasen	5	0.1
Vogelschutzzonen	9	0.15
Wald	0	0.13

How a cost surface is built



Cost Surface

Weight Table

Feature Class	Resistance	Feature Weight
Bauland_Siedlungen	9	0.06
Feuchtgebiete	7	0.2
Freizeit_Wasser_b	8	0.22
Gewaesser_Gewaesserschutz	7	0.05
Hochwasserzone_030a	2	0.41
Hochwasserzone_100a	2	0.31
Hochwasserzone_300a	5	0.28
Kulturlandschaften_2	4	0.12
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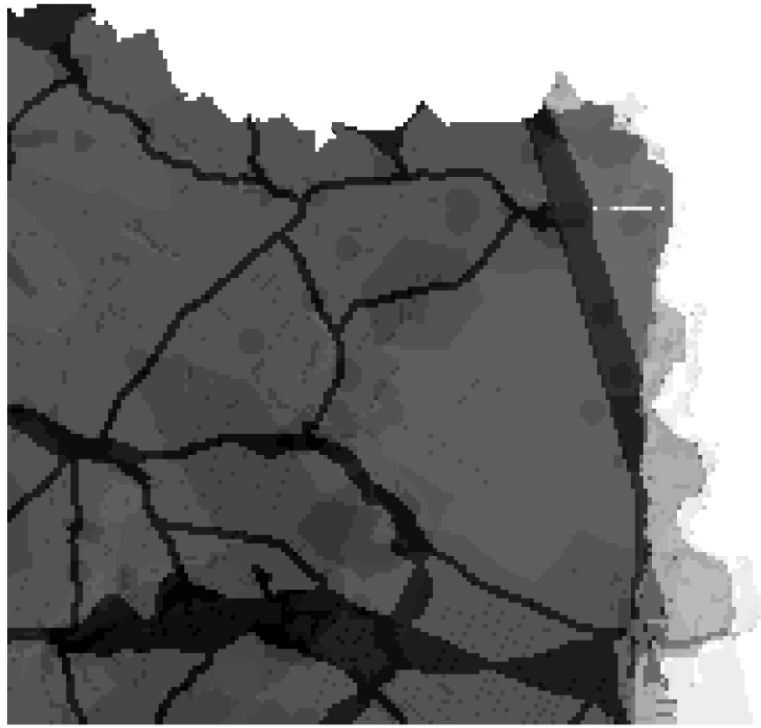
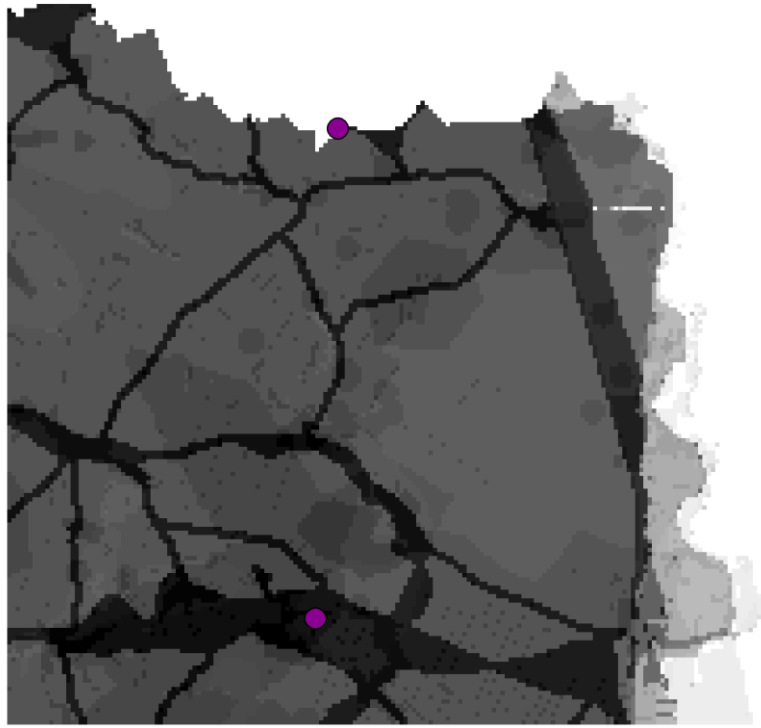
How a cost surface is built



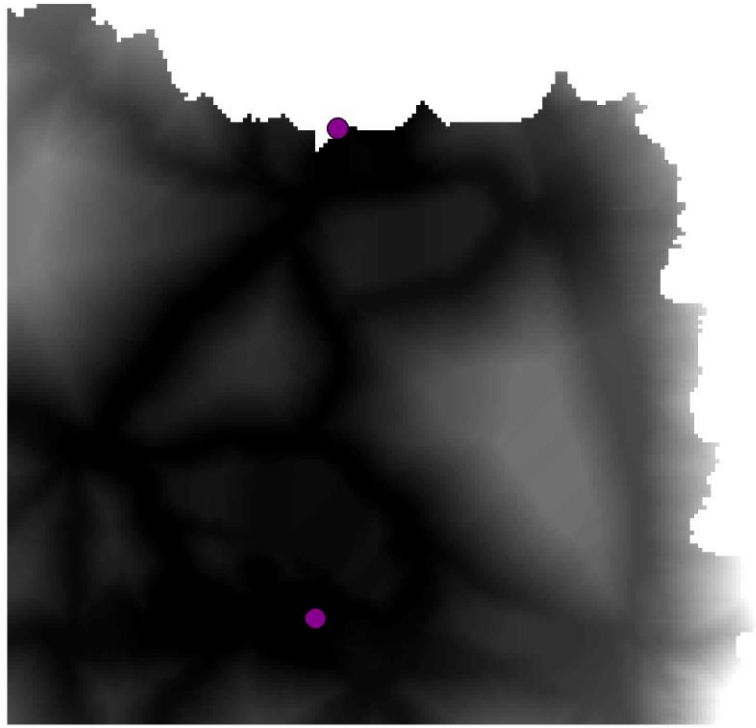
Cost Surface

How a cost surface is built



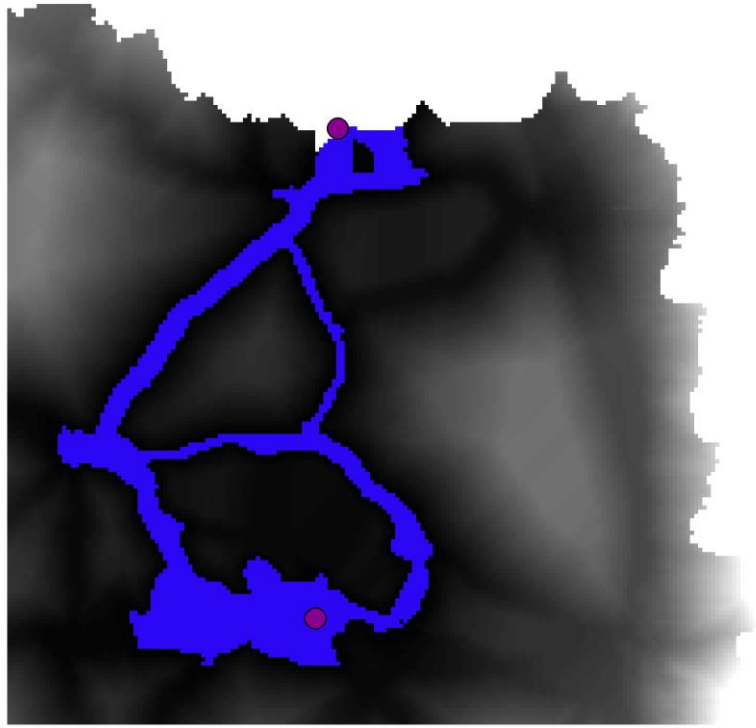
Cost Surface

How a cost surface is built



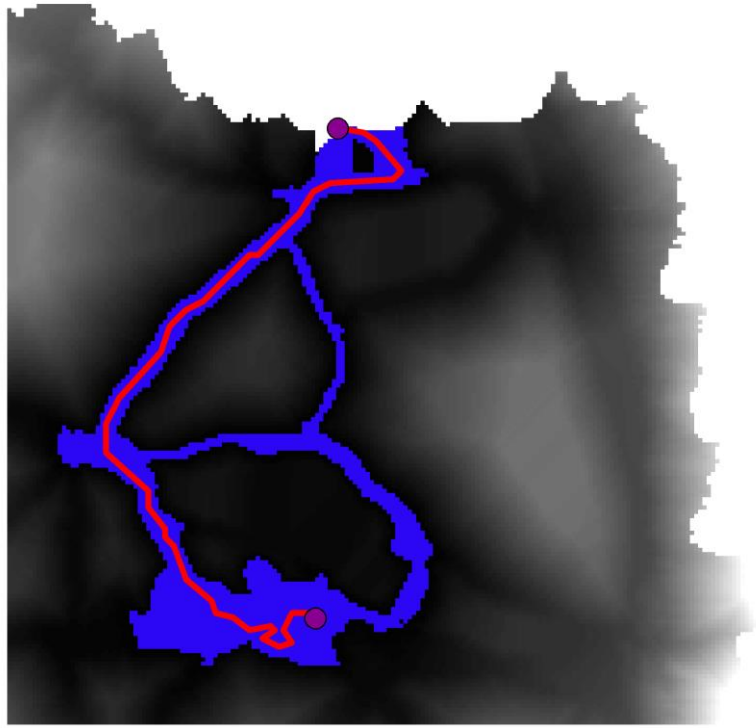
Global Cost Surface

How a cost surface is built



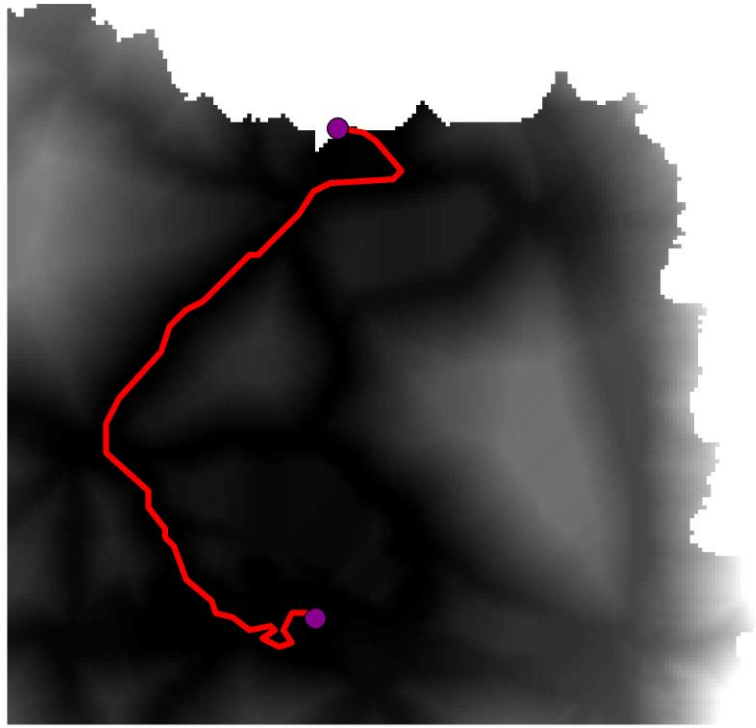
Global Cost Surface + Corridor

How a cost surface is built

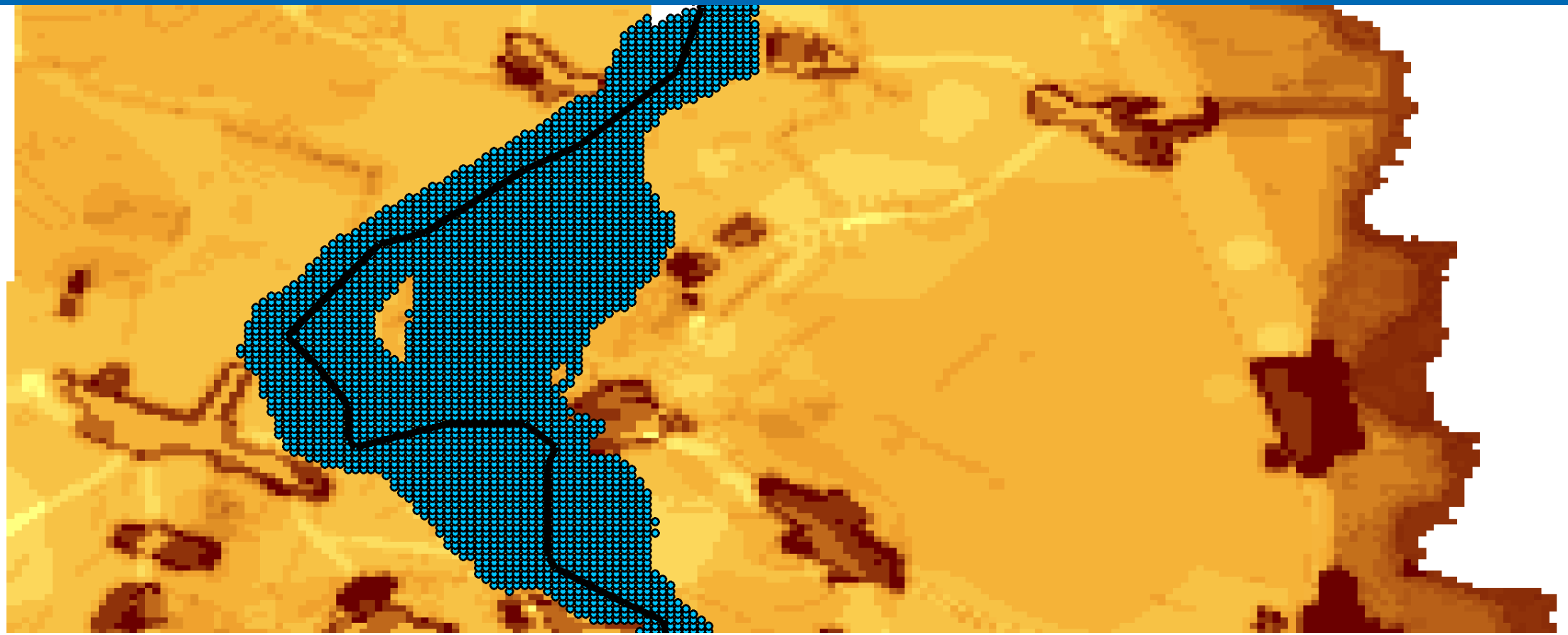


Global Cost Surface + Corridor + Path

How a cost surface is built



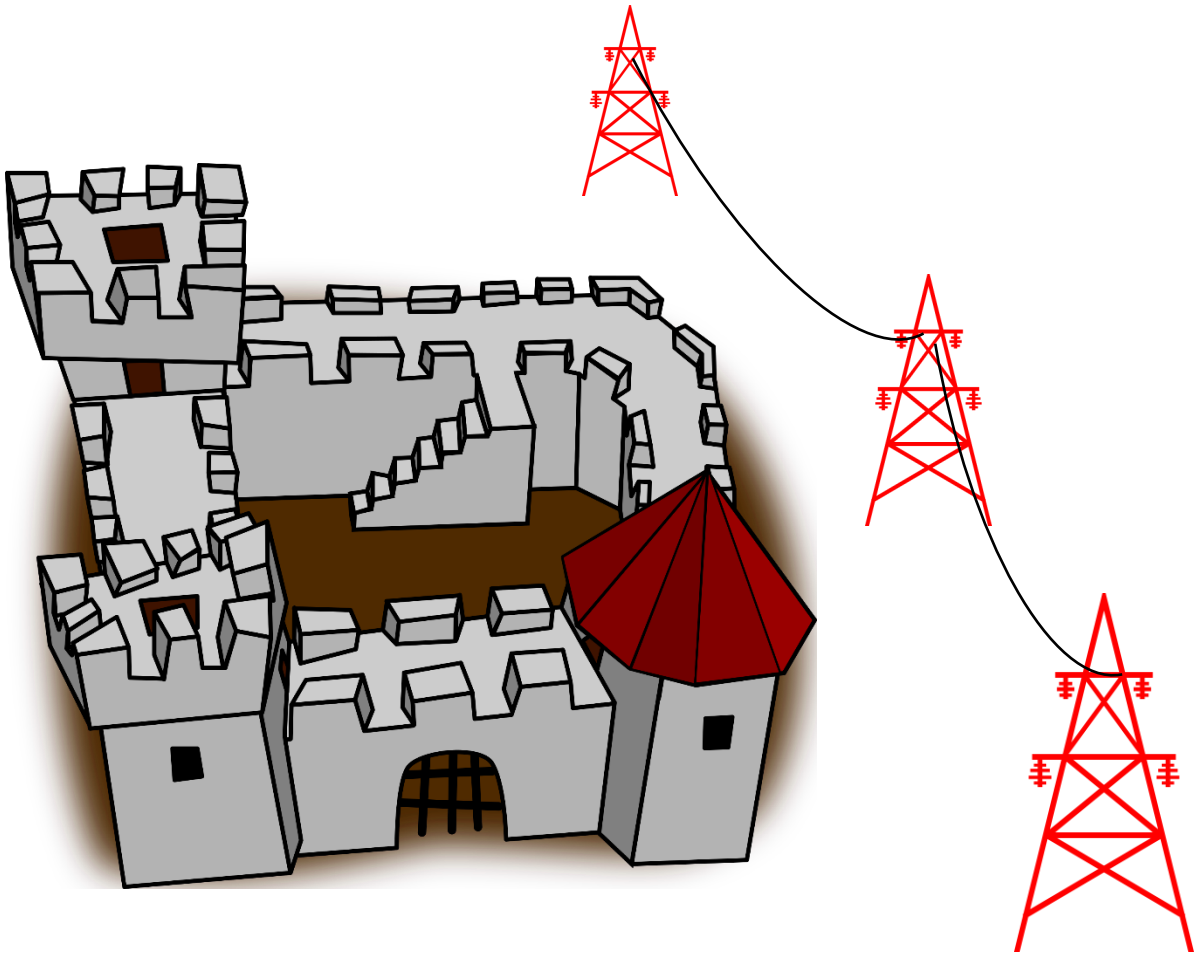
Global Cost Surface + Path



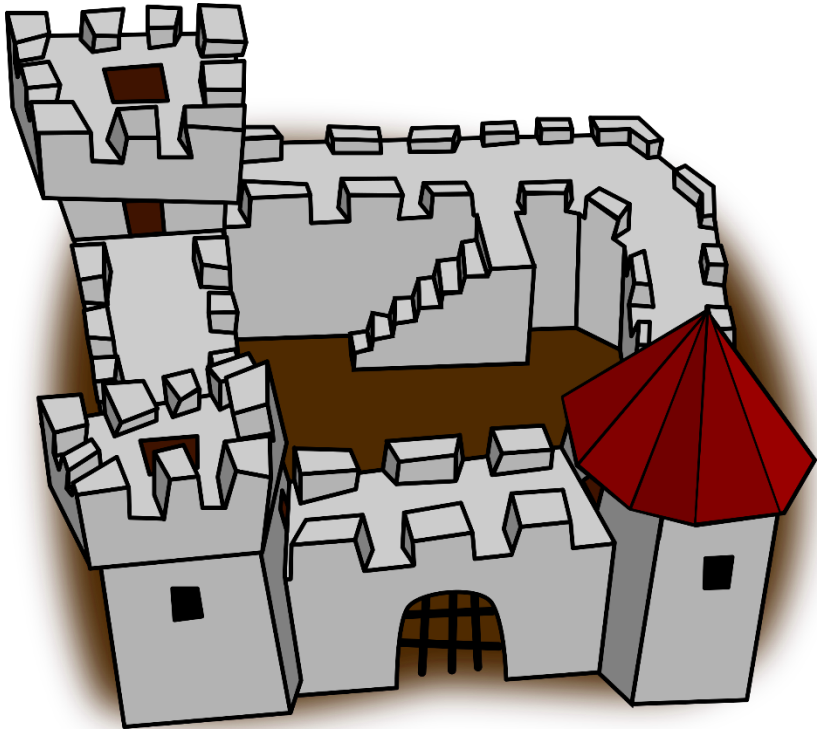
Proximity Effect

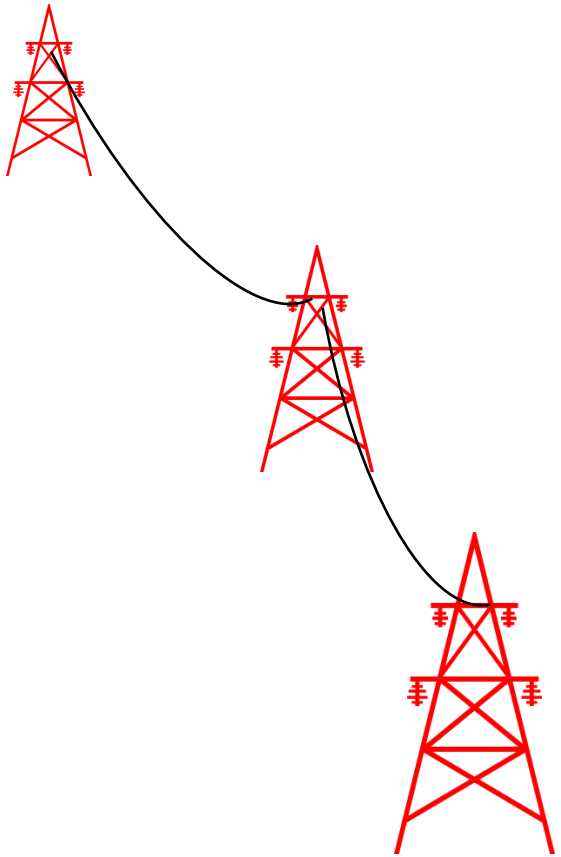
Why the consideration of a buffering concept makes transmission line modeling more realistic

Would you be bothered if a power line was built beside your beautiful castle?

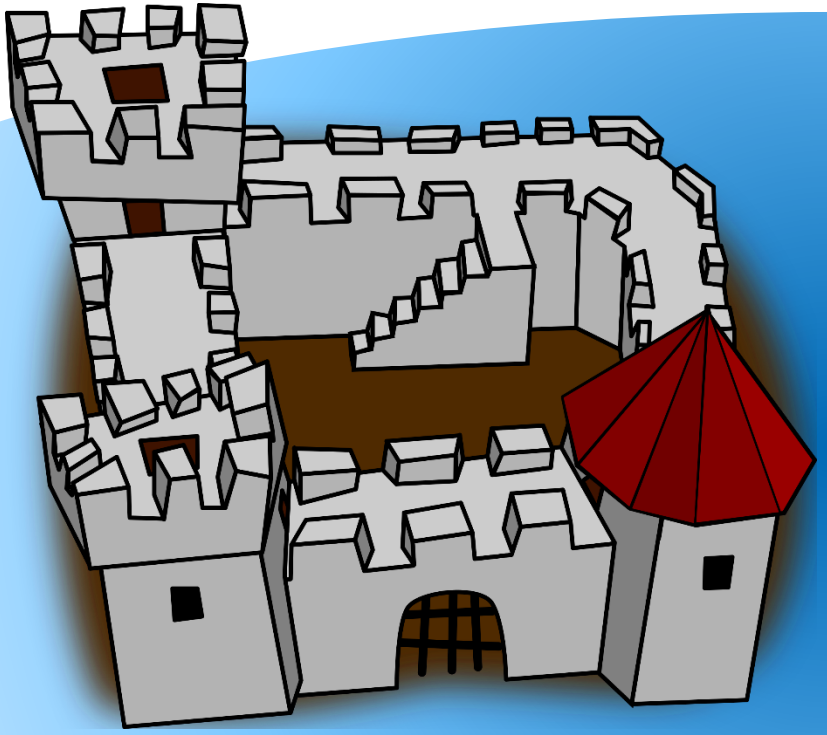


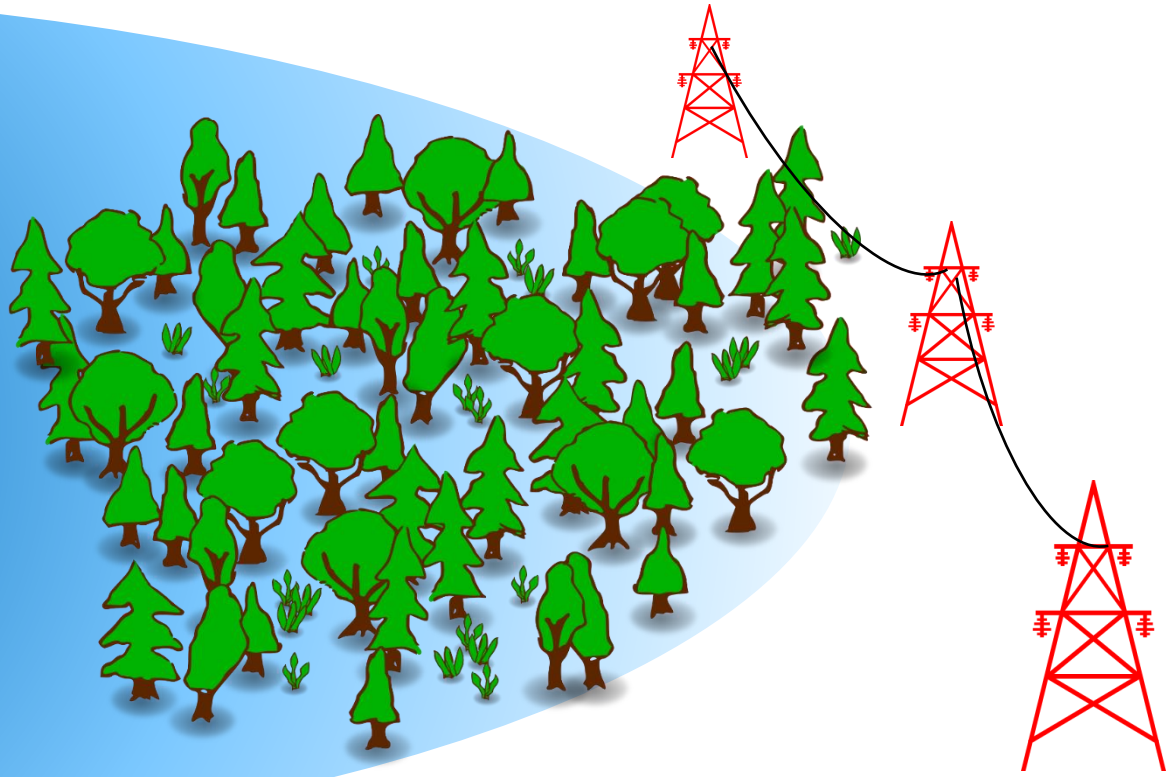
Would you be bothered if a power line was built beside your beautiful castle?



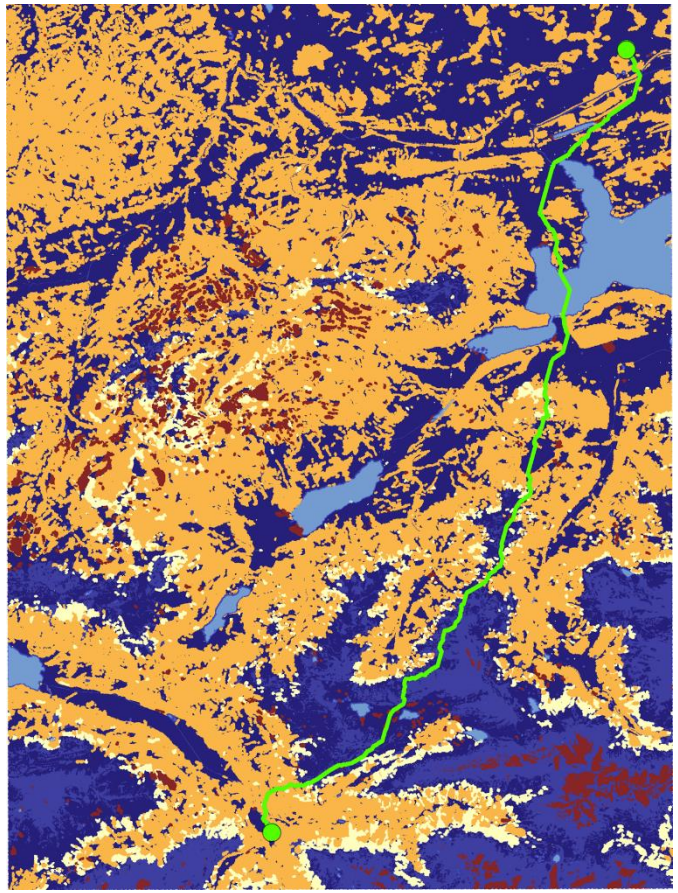


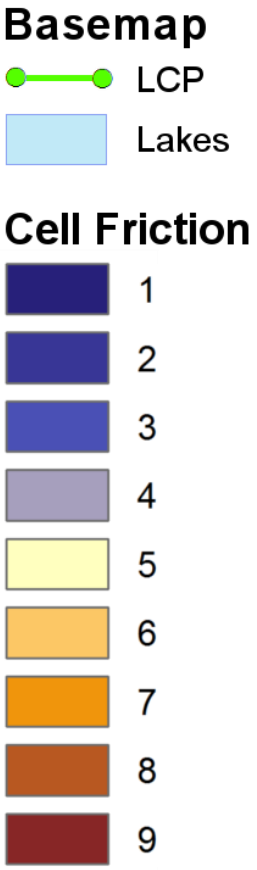
Would you be bothered if a power line was built beside your beautiful castle?

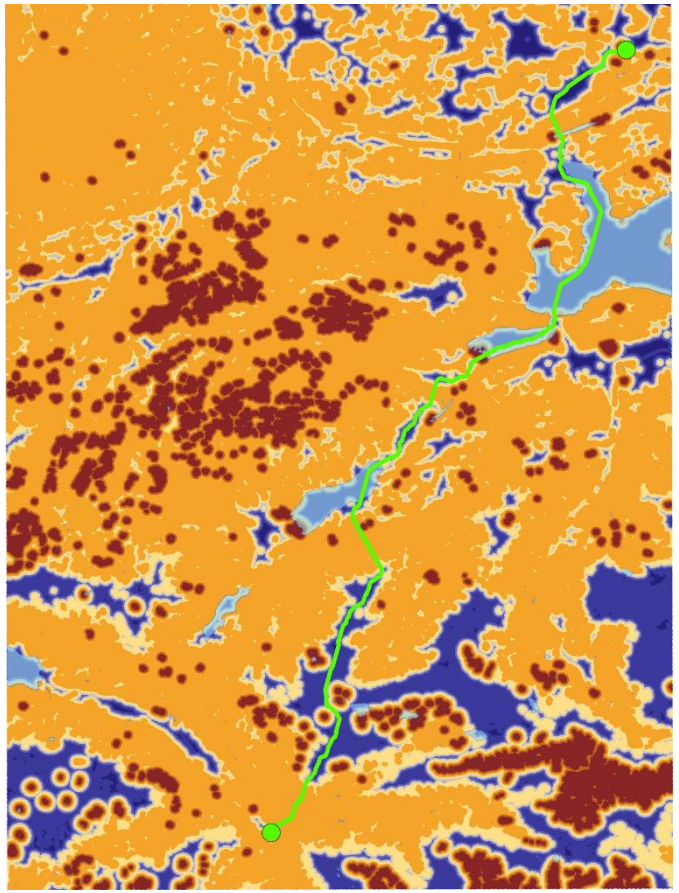




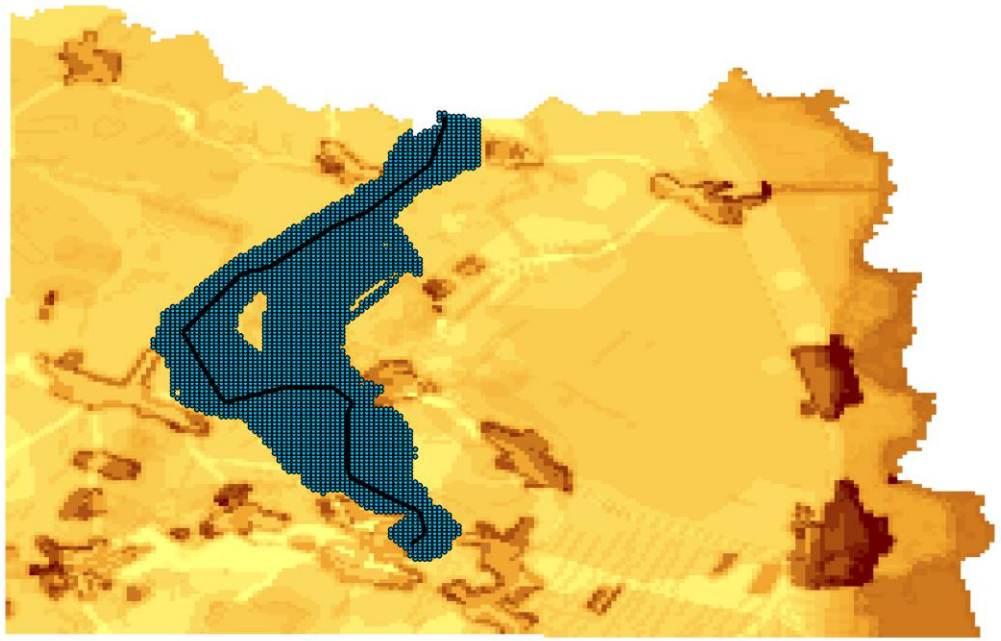
Demonstration



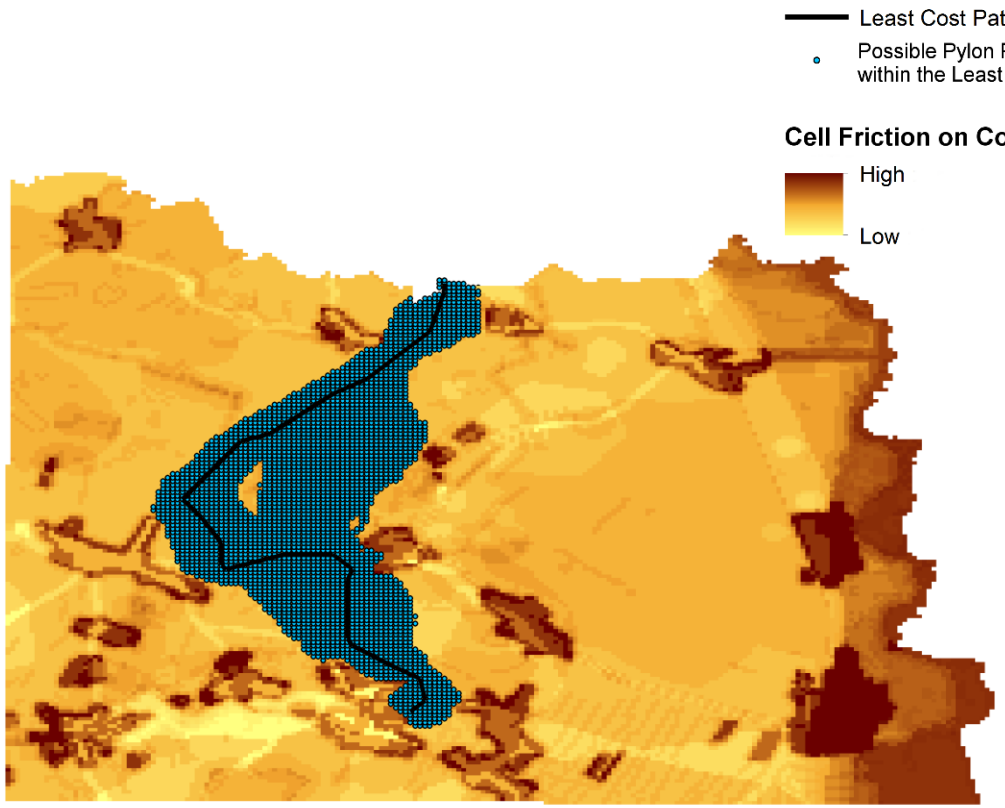




Integrating the proximity concept based on Tobler's First Law of Geography

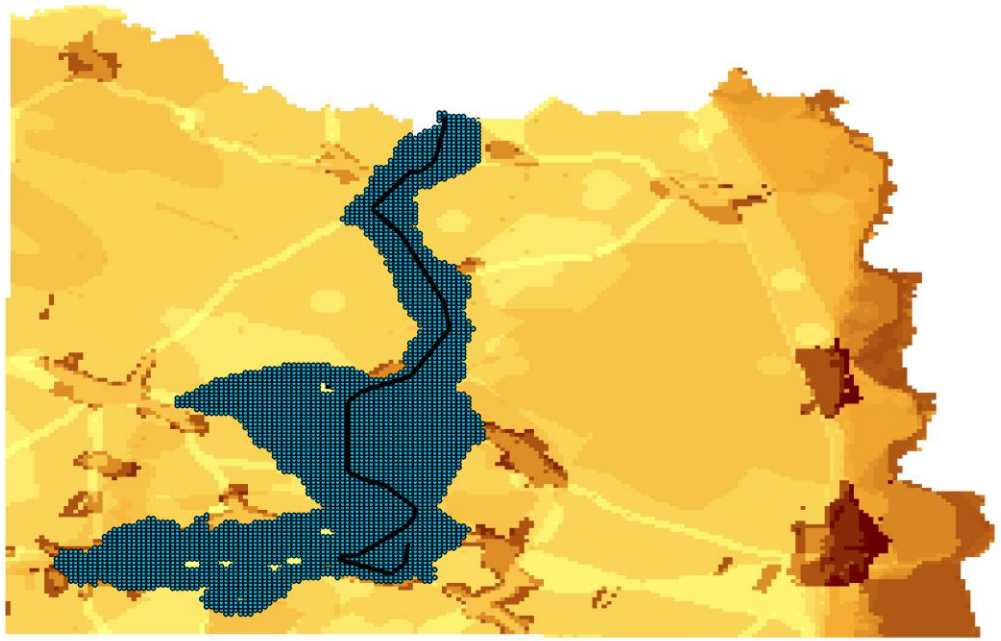


Maximum value chosen

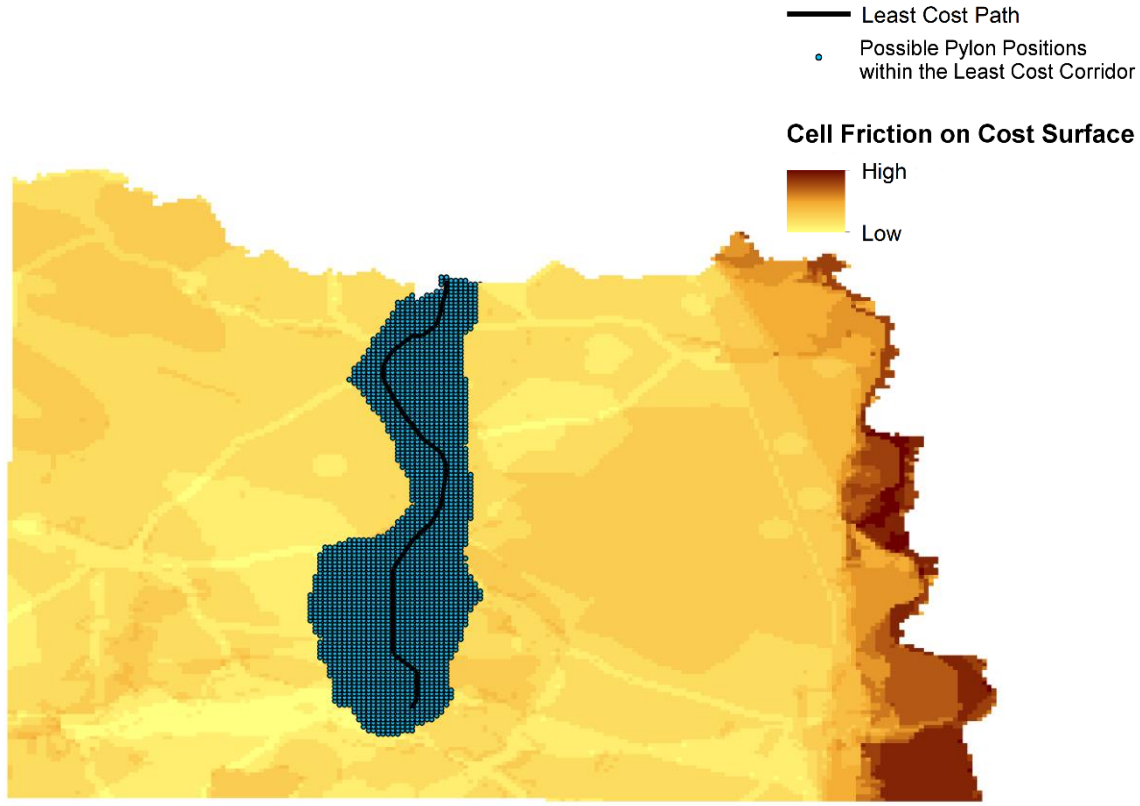


Simple additive weighting, by reducing weighting the more frequent a cell overlaps

Choosing a model with sharp boundaries



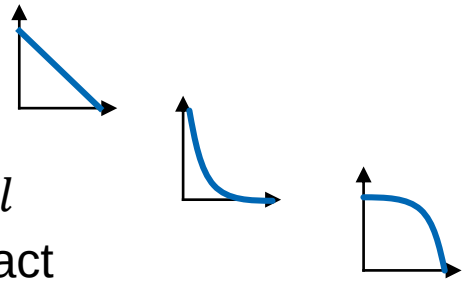
Maximum value chosen

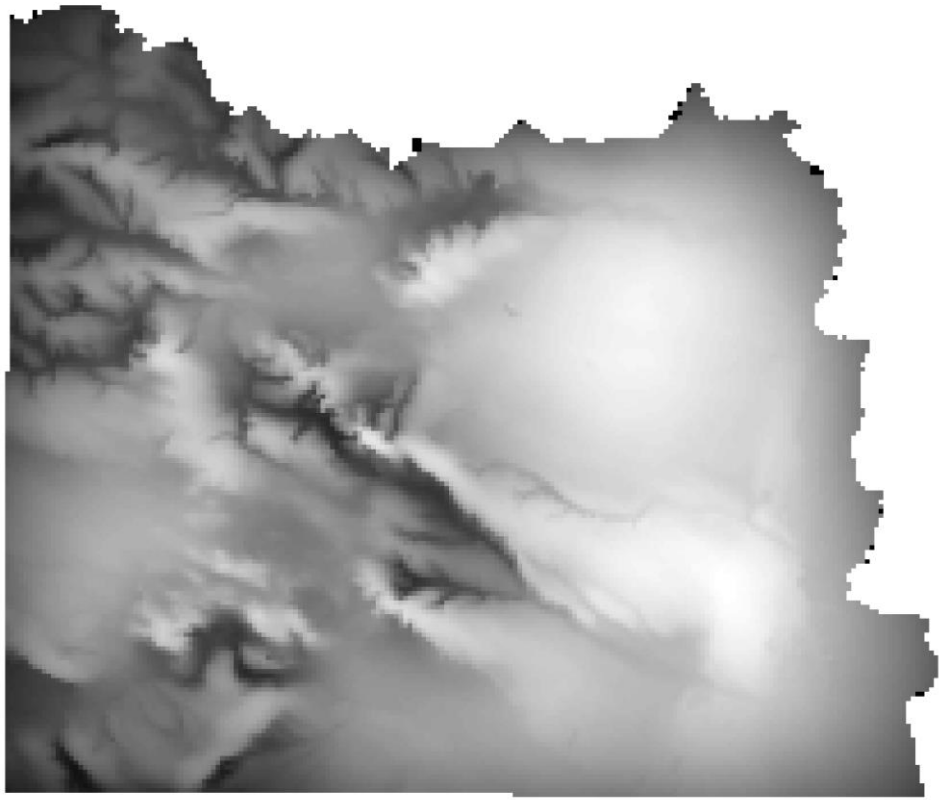


Simple additive weighting, by reducing weighting the more frequent a cell overlaps

A look at the curve valuation of the visibility impact

- How probable is it to see a specific location 30 m above the ground if observers stay more often in area A than area B?
- Integrate different valuations:
  - linear
  - exponential $-e^{c \cdot p} + q = maxVal$
  - logarithmic $-c \cdot \ln(p) + q = maxVal$
  - x-axis: distance / y-axis: visual impact
  - done by numeric method
- First results: no big difference. More structured test are needed.





Develop 3D DSS Platform

Results of Workpackage 3

Develop 3D DSS Platform = Workpackage 3

WP1

WP2

WP3

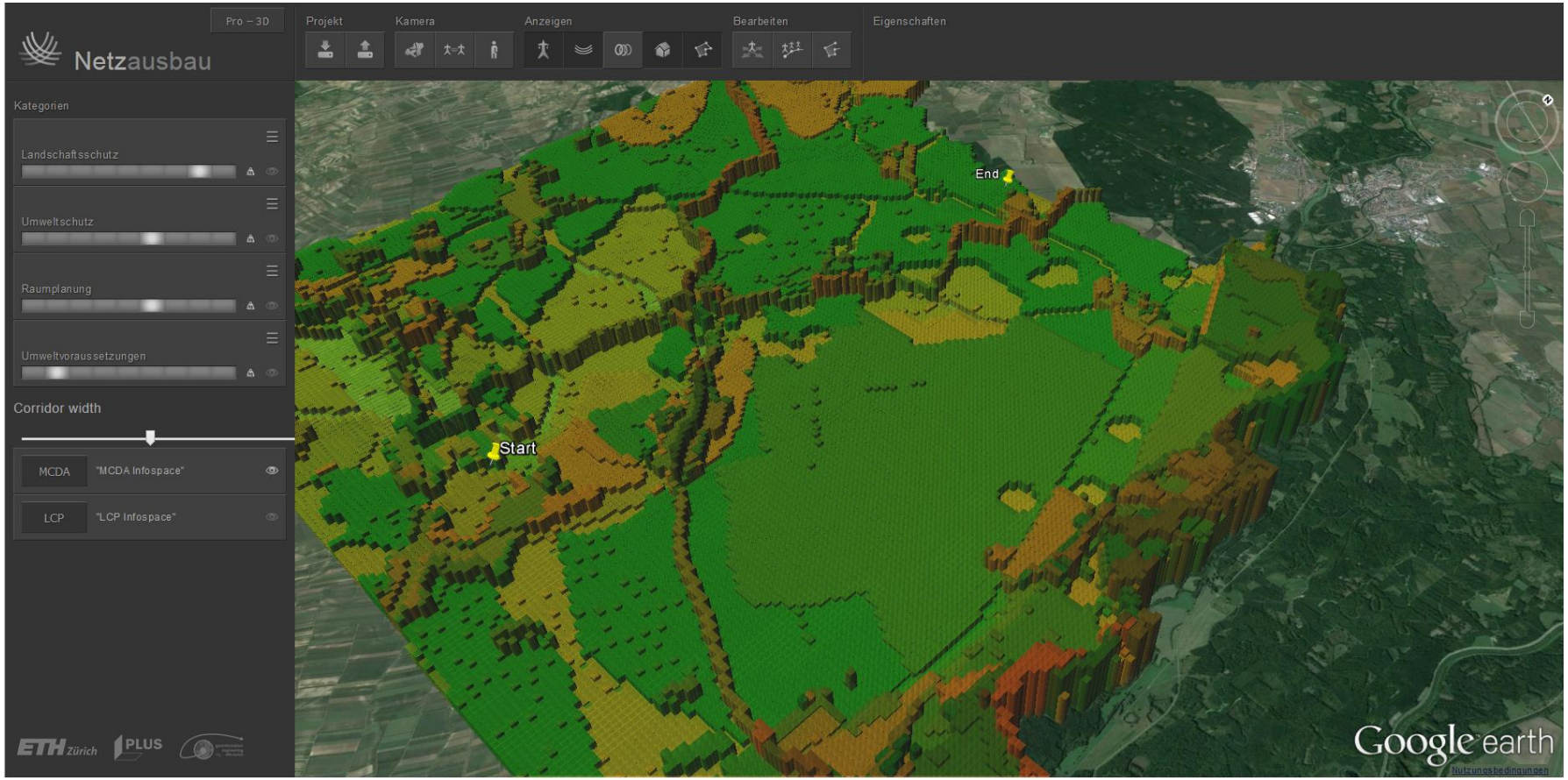
- Develop a web-based, collaborative 3D DSS, and visualize the results of WP2

WP4

- Steps
  - Set up interactive, web-based solution
  - Visualize LCC&LCP generically using Google Earth

Result: netzausbau.ethz.ch works

→ Are you ready for the demonstration?

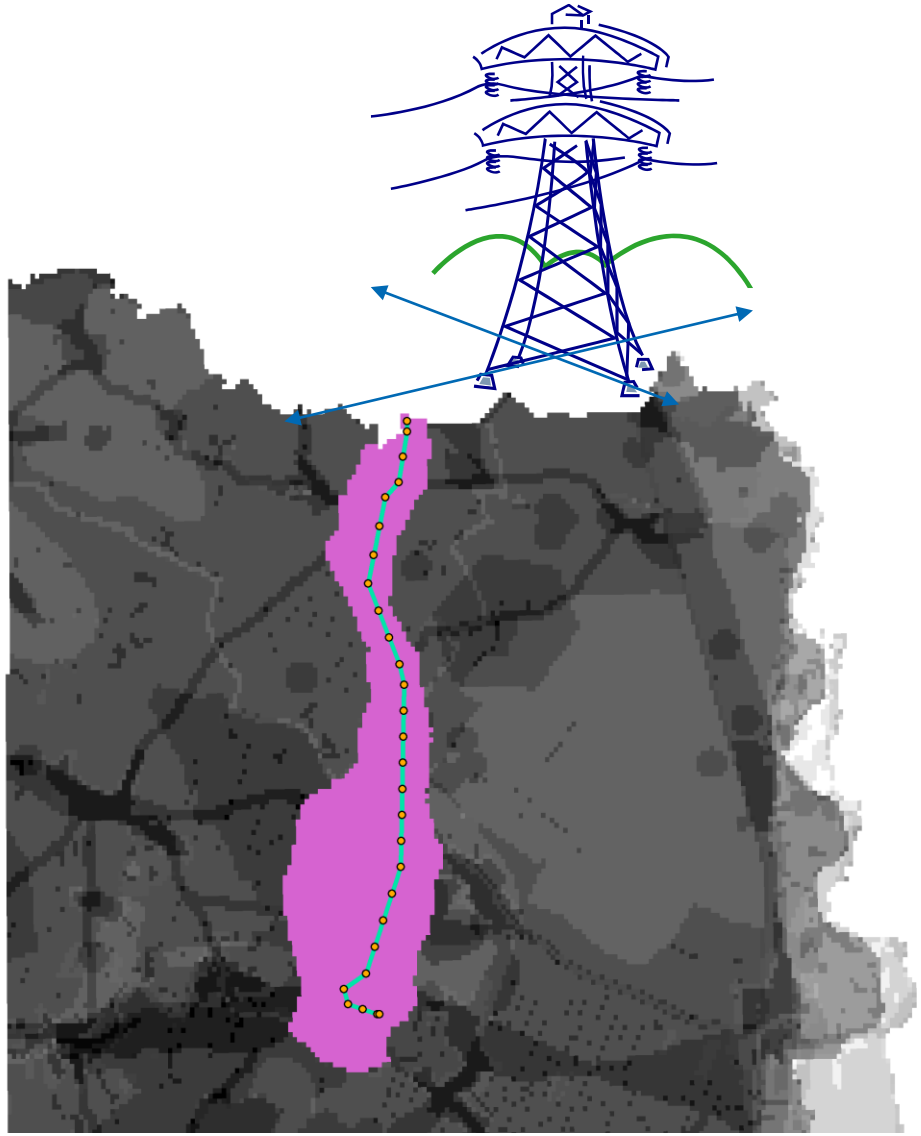


Future Outlook

On WP3 & WP4

Key concept: Transmission tower siting

- A simple approach calculates the position of the transmission towers.
- However, it must be optimized since the solutions are not realistic. They do not yet consider the DEM.
- A master student is elaborating an method to optimally site transmission towers.



Imagine an application in which a power grid could be planned in 3D and allows

Interaction

Communication

Data Integration

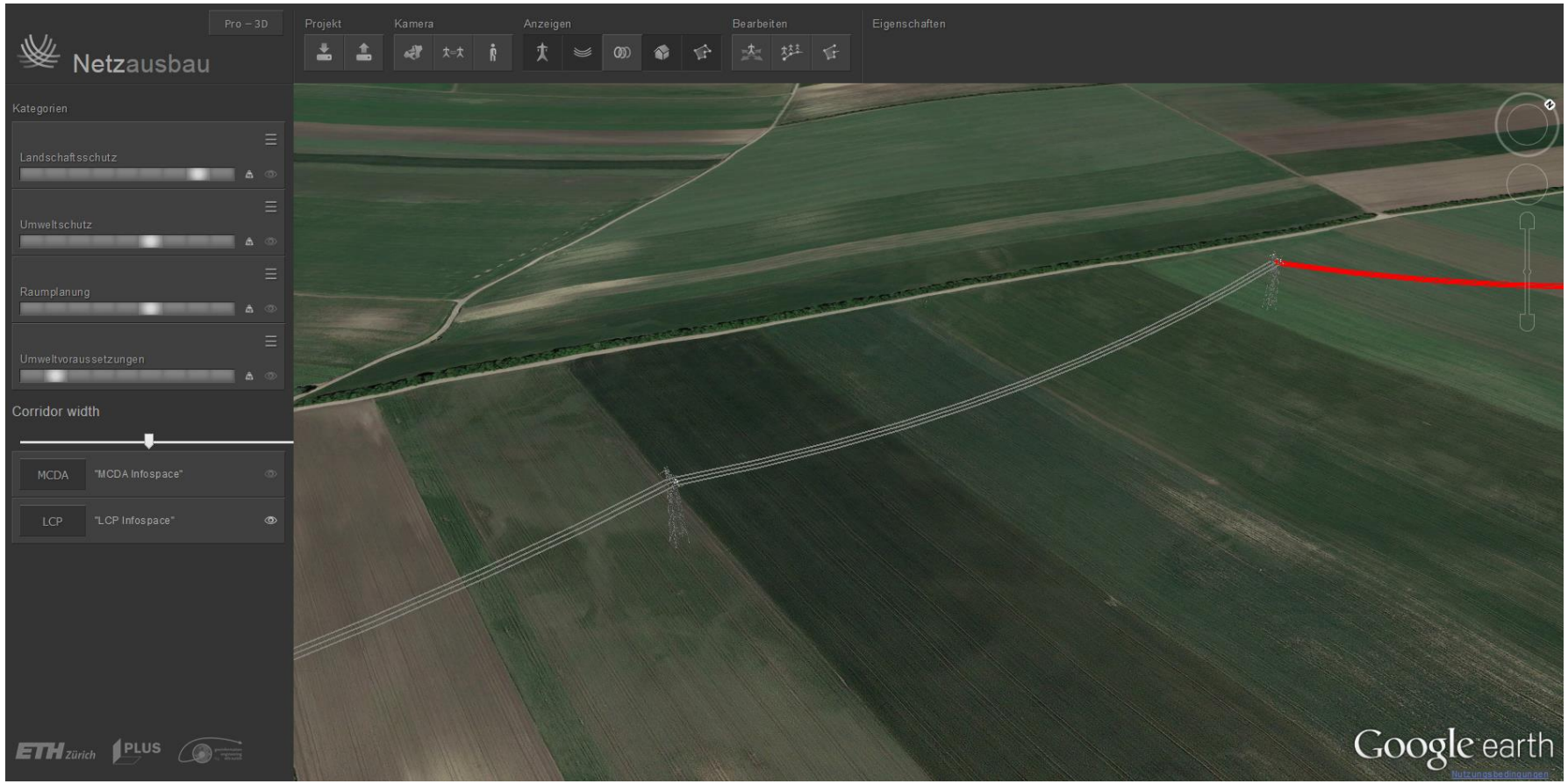
Realistic Impressions

LiDAR Data Integration

Exchange of Ideas

Weighting

Cost Estimation



Discussion

Open Questions? Don’t hesitate to ask.

Thank you for your attention