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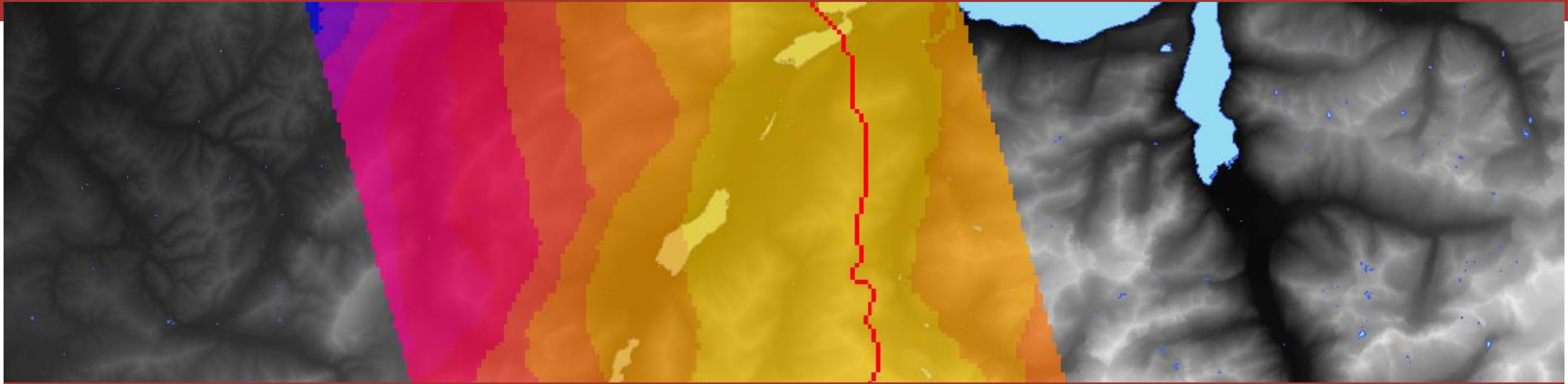

Application of 3D Geographic Information Systems for transparent and sustainable planning of electric power systems

23.02.2016, Zurich

Project Presentation at ETH Zurich

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Agenda

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

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Project Background

Introduction to the goals, the context, and the problems

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Imagine an Application in which a Power Grid Could Be Planned in 3D and Allows

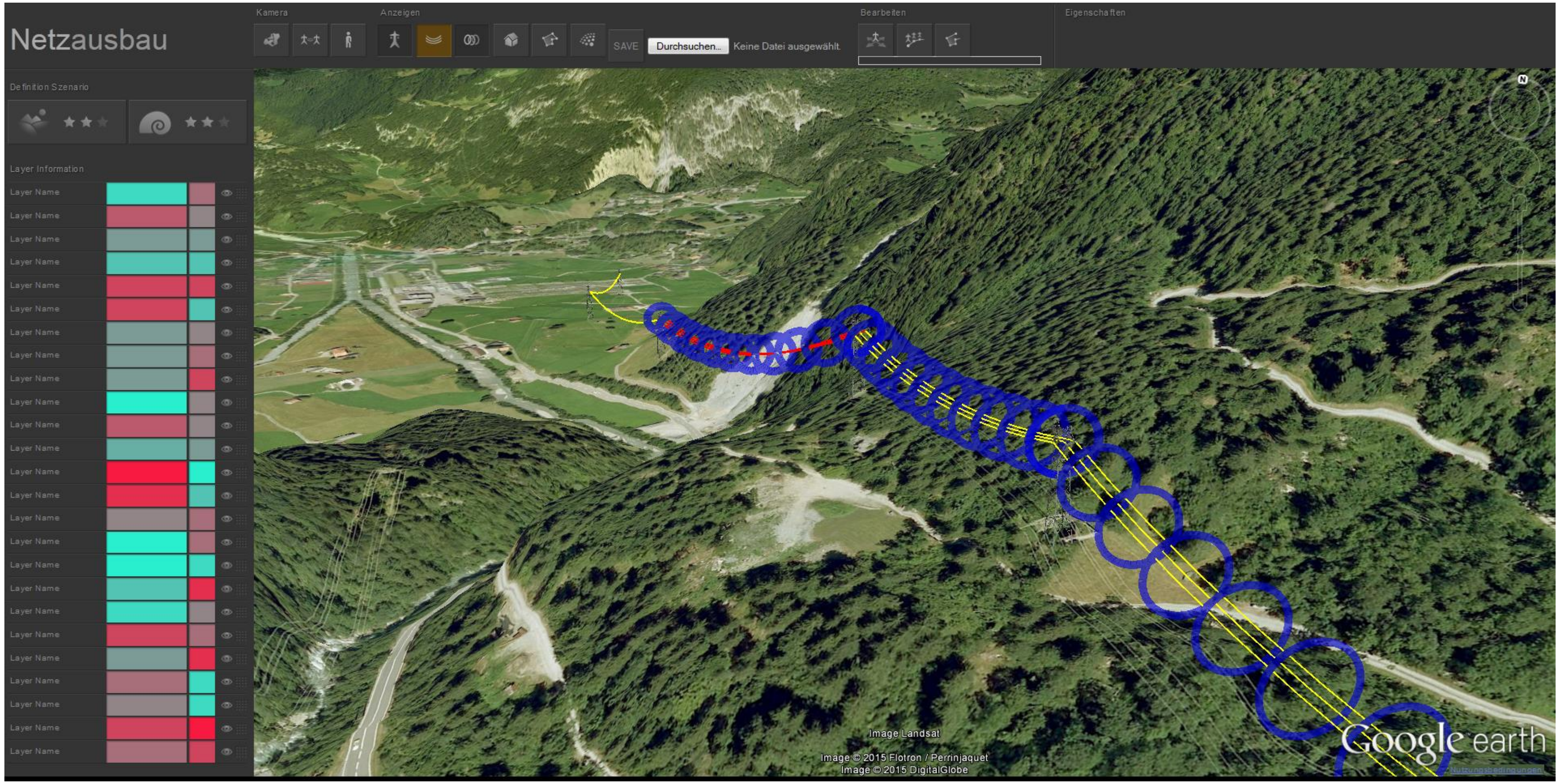
Interaction

Communication

Data Upload:
SHP, CSV, Pylons

Realistic
Impressions

LiDAR Data
Integration



Exchange of
Ideas

Weighting

Cost
Estimation

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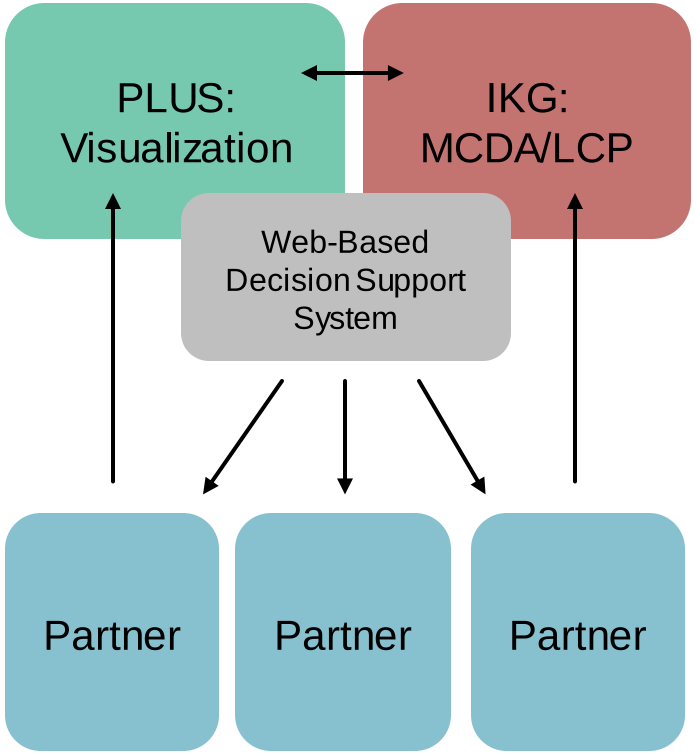
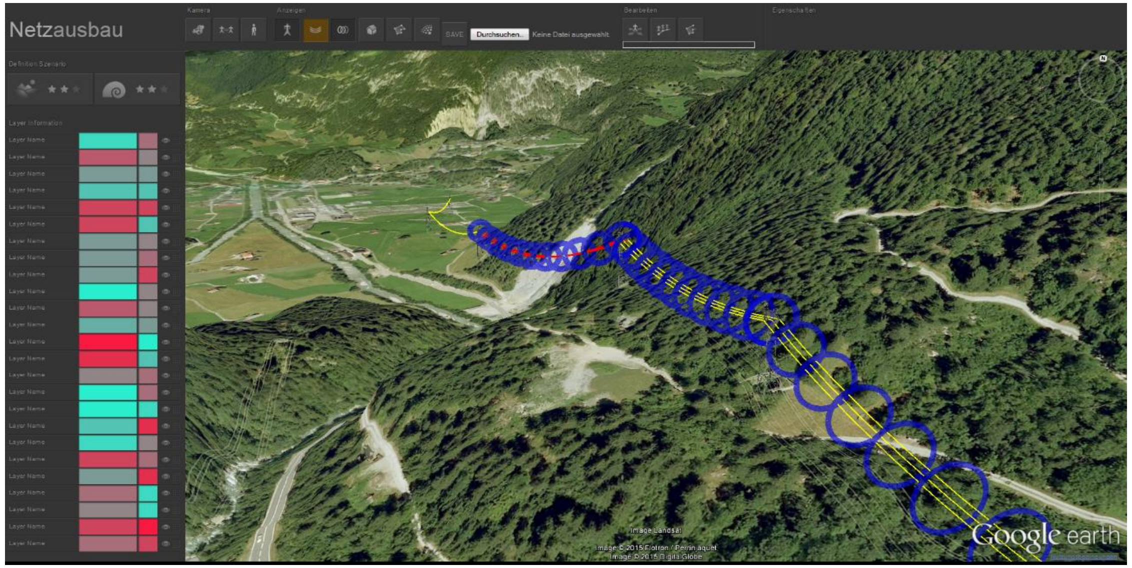
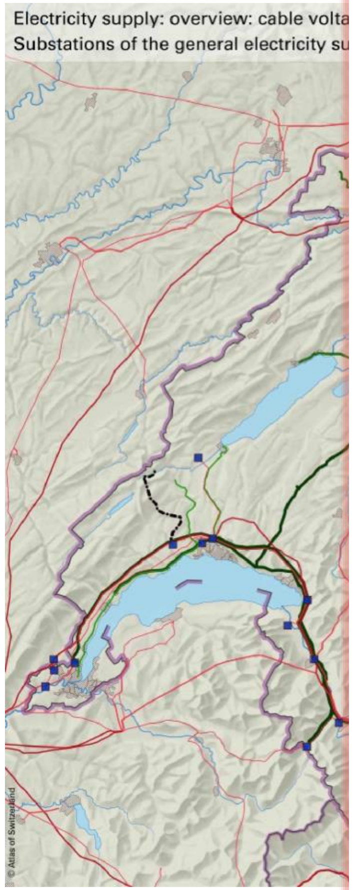
2 Teams Are Working on the Project

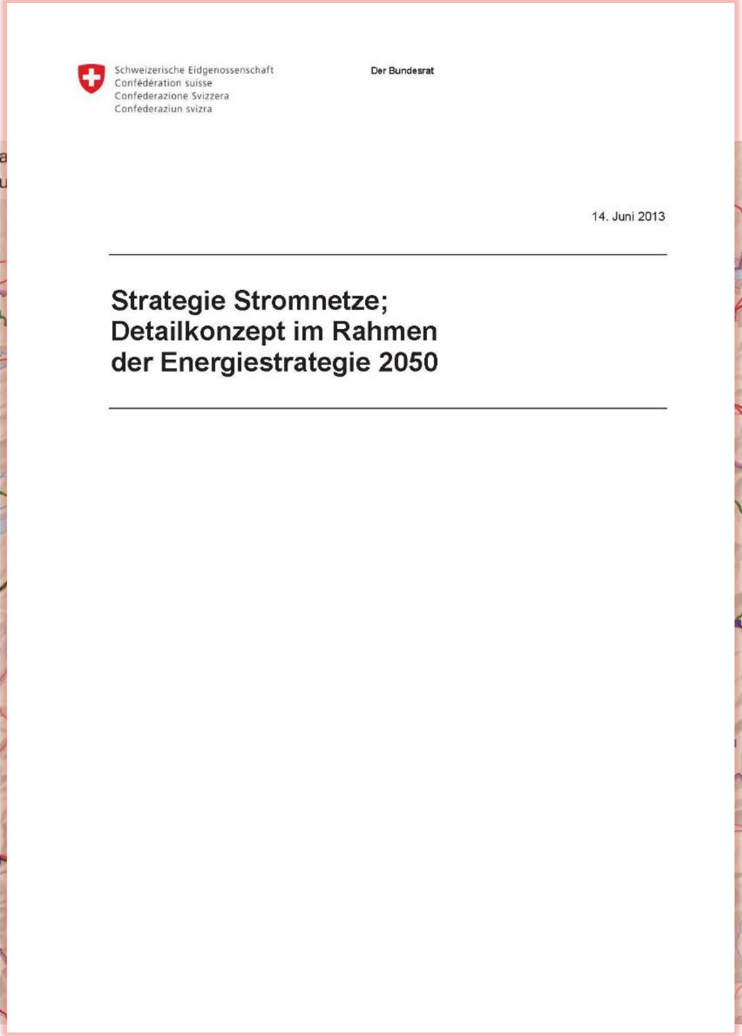




Background: The Power Grid Must Be Extended

swissgrid

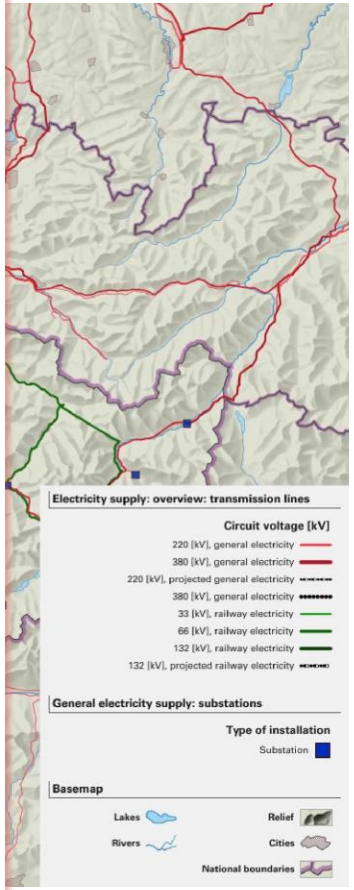



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Der Bundesrat

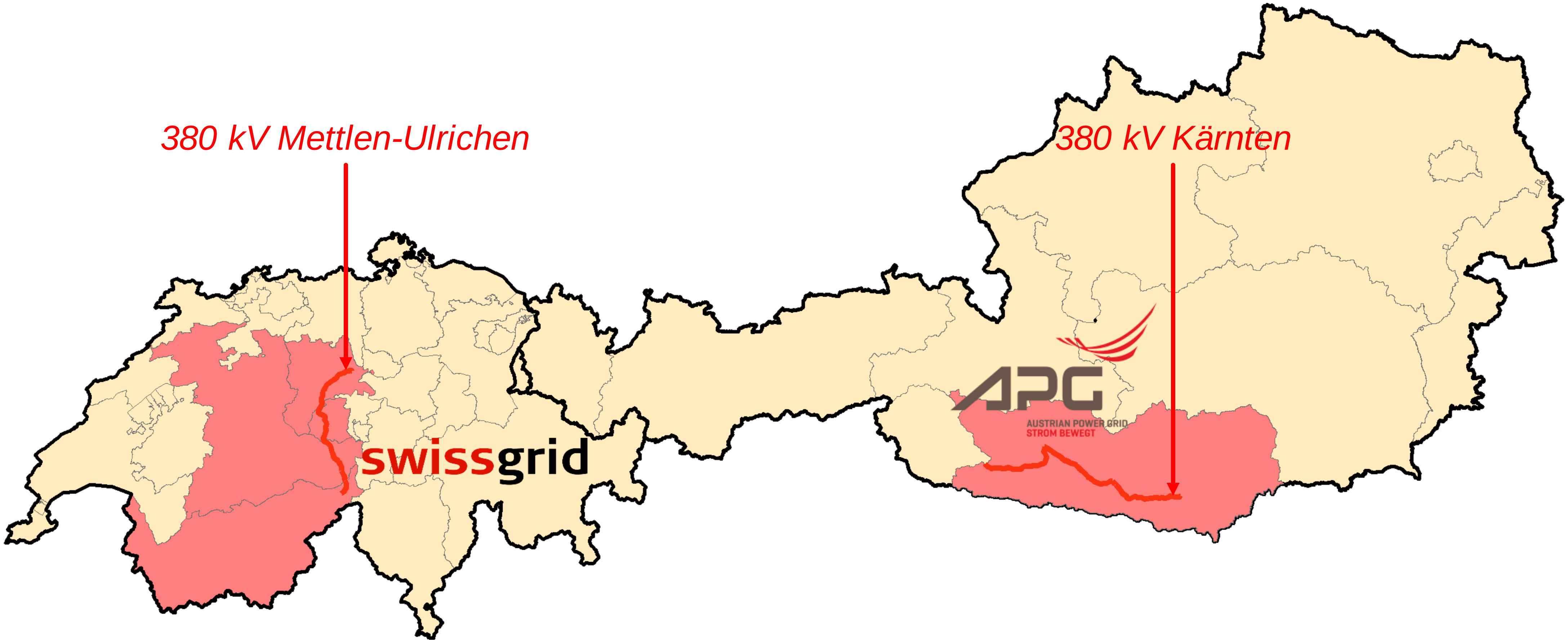
14. Juni 2013

Strategie Stromnetze;
Detailkonzept im Rahmen
der Energiestrategie 2050

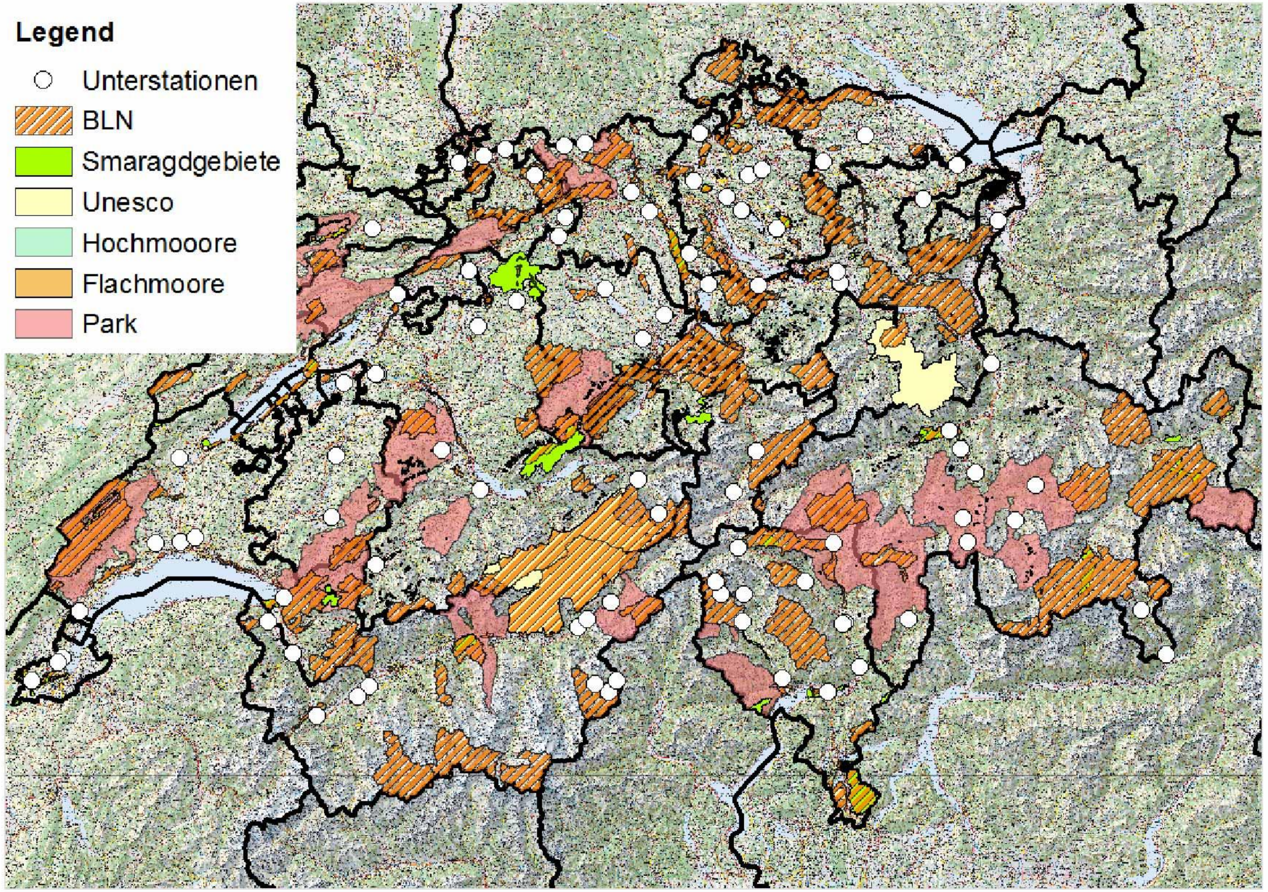


Source: Atlas der Schweiz 3

We Focus on the Grid Renewal and Expansion in Switzerland and Austria



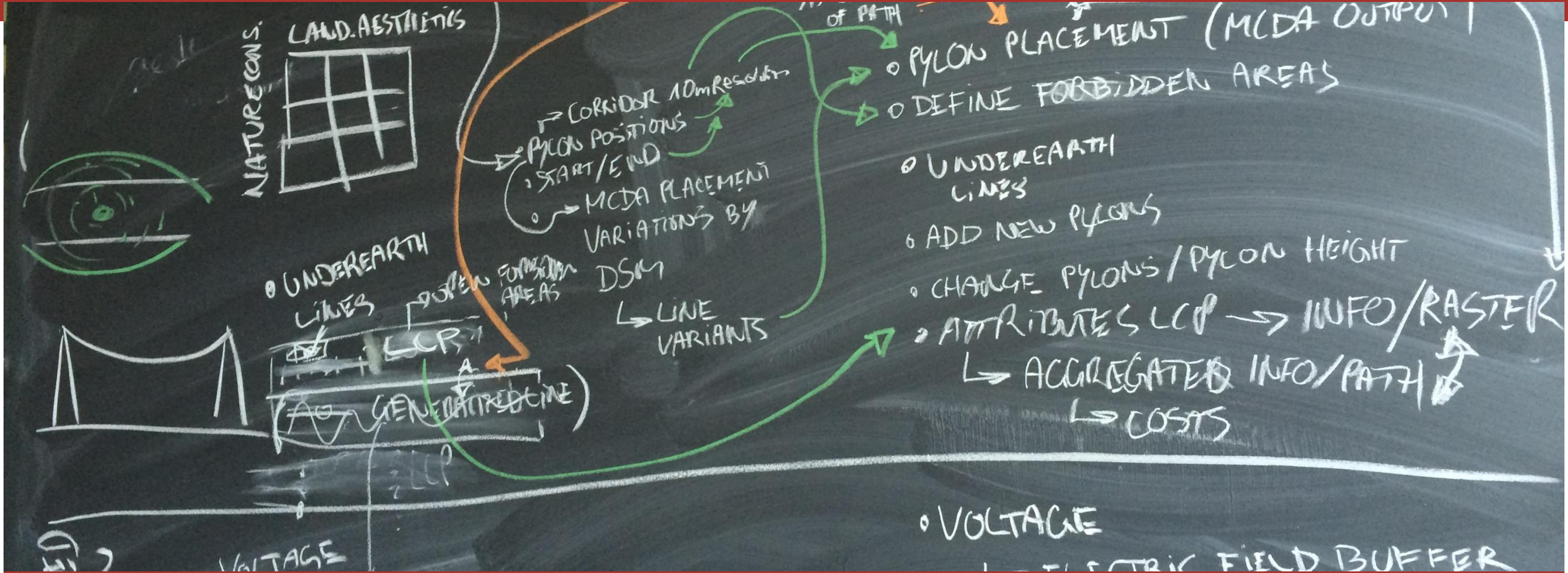
Problems: Spatial Constraints, Laws, Protective Measures and Different Interests



Source: Master Thesis Zoran Brankovic (2013)

General Constraints:

- Legal regulations
- Spatial obstacles (protected areas, lakes, settlements, etc.)
- Subjective interests of stakeholders
- Conflicts of interest
- Large distances
- **High effort, high costs**

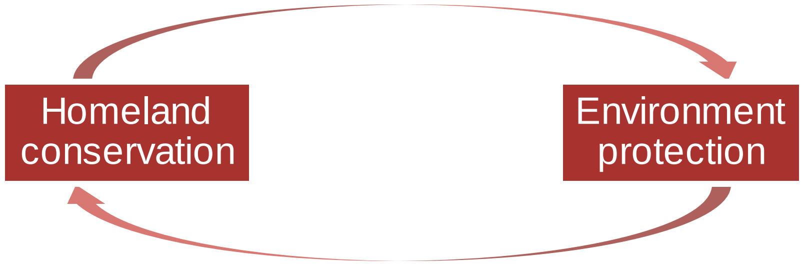


Concept

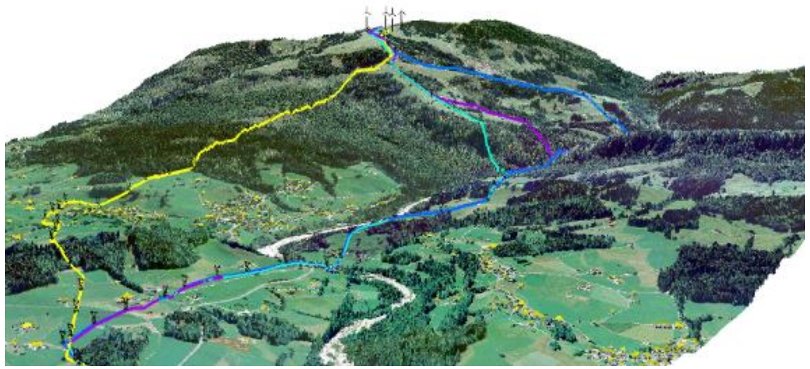
Introduction to the goals, the context, and the problems

Interaction between User and DSS

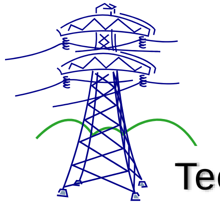
- Inputs
  - Start, end, constraining points, voltage
  - Additional data: Shapefiles, Tables, Pylons
  - Layer and category weights
- MCDA → Least Cost Corridor + Least Cost Path
  - A *Cost Surface* is computed through MCDA
  - A *Least Cost Corridor* and a *Least Cost Path are derived*
- Output
  - 3D-Visualization with suitable corridor, path and pylon positoin
  - Costs: monetary and in terms of ecosystem services
  - Additional information per cell



Scenario	Homeland	Nature
Profile 1	*Weighting 1.1*	*Weighting 1.2*
Profile 2	*Weighting 2.1*	*Weighting 2.2*
Profile 3	*Weighting 3.1*	*Weighting 3.2*



4 Factors Are Considered in the Multi-Criteria Decision Analysis



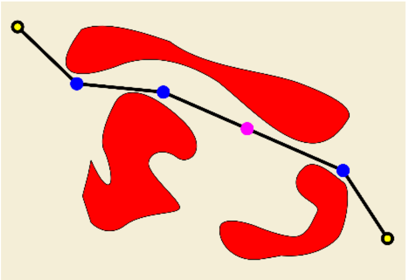
Technical Constraints

Monetary Costs

Ecological Impact

Social Impact

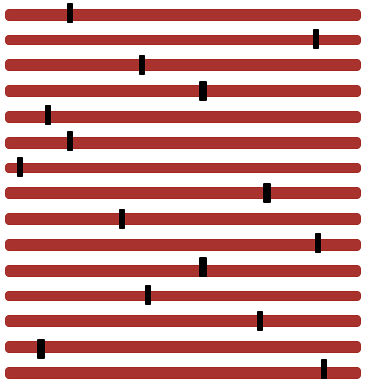
Restricted Areas
Minimum and Maximum Values



Dependent Variables

***f(x)* = …**

Independent Variables



Goal: Set the Variables Advantageously for all Stakeholders to Reduce the Number of Objections

citizens can use right of veto to impede a project

additional costs

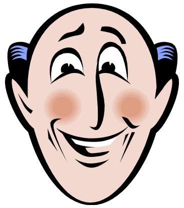
3D DSS saves time and promotes citizens' acceptance

3D DSS offers realistic visualizations in 3D

3D DSS counteracts the urban sprawl by preferring existing linear infrastructure corridors

3D DSS allows concept transfer to other linear infrastructure

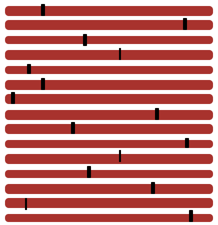
instead

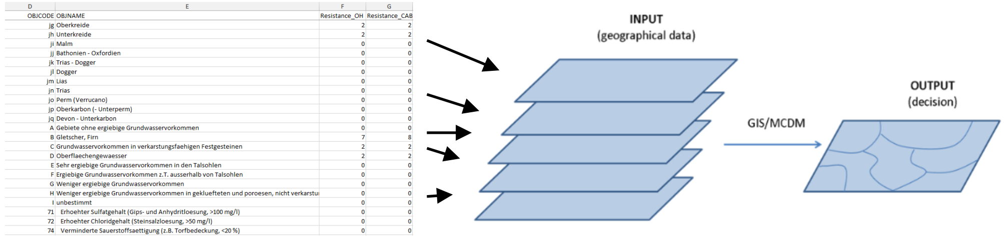


foster transparency

integrate the citizens in the planning process

allow communication between the stakeholders





Procedure: Project Work Packages over 3 Years

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

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

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

WP4
- Convey interviews with stakeholders and evaluate case studies

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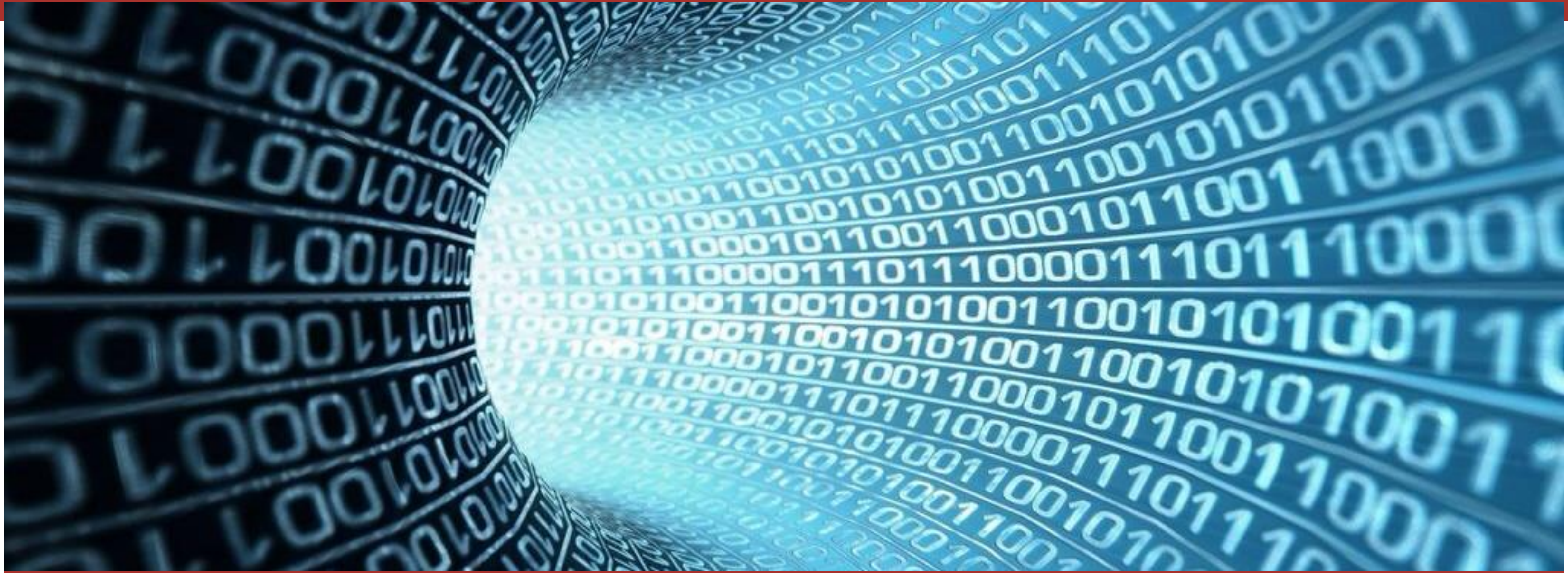

Data Mining

Results of Workpackage 1

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Data Mining = Workpackage 1

WP1

- Examine needs, collect data and create a geodatabase structure

WP2

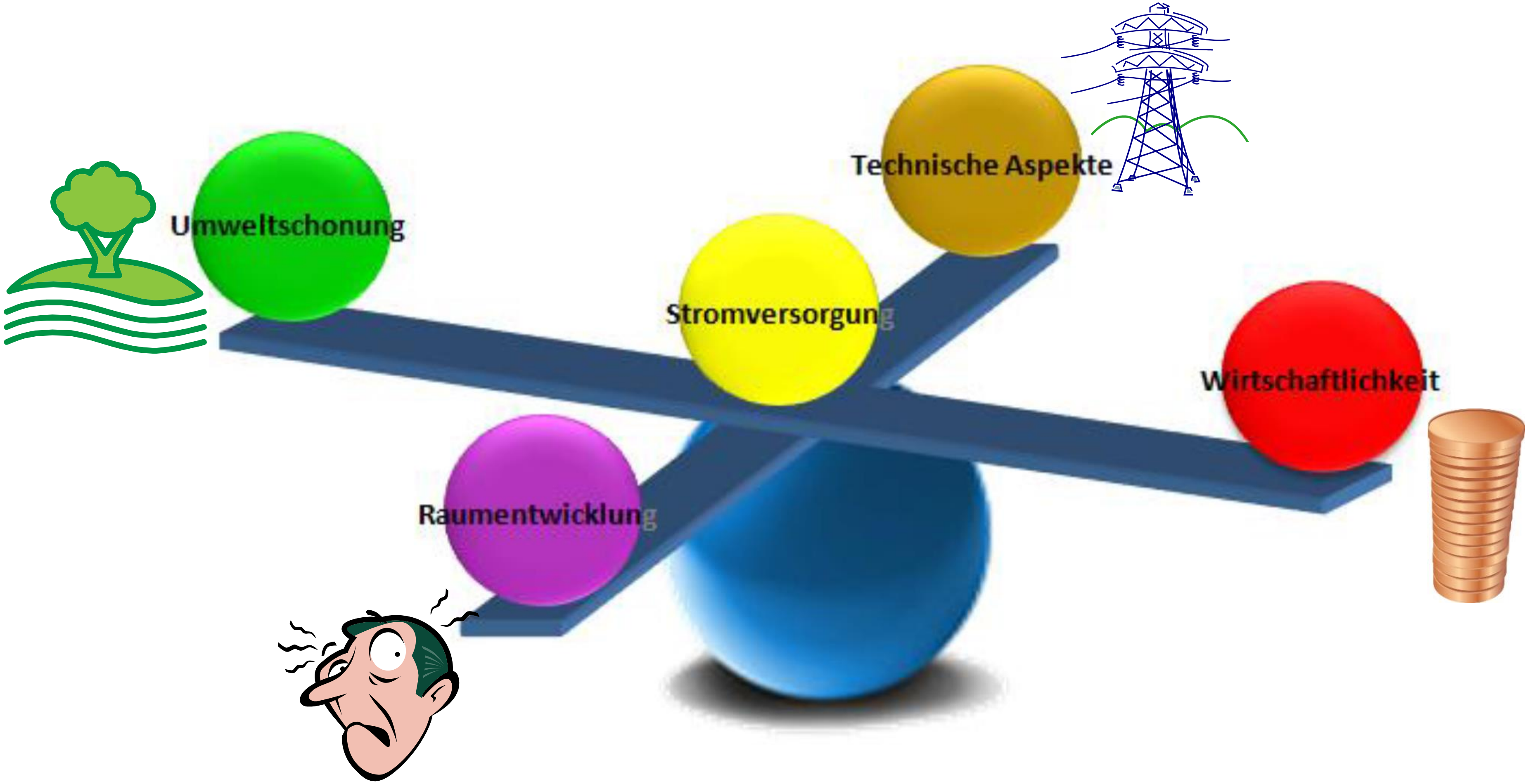
WP3

WP4

- Steps

  →Define the project's framework
  →Create a data handling concept
  →Collect, analyze, and standardize data / attributes
  →Report metadata, create a guideline
  →Clarify legal issues

Four Factors Must Be Balanced to Obtain Power Supply

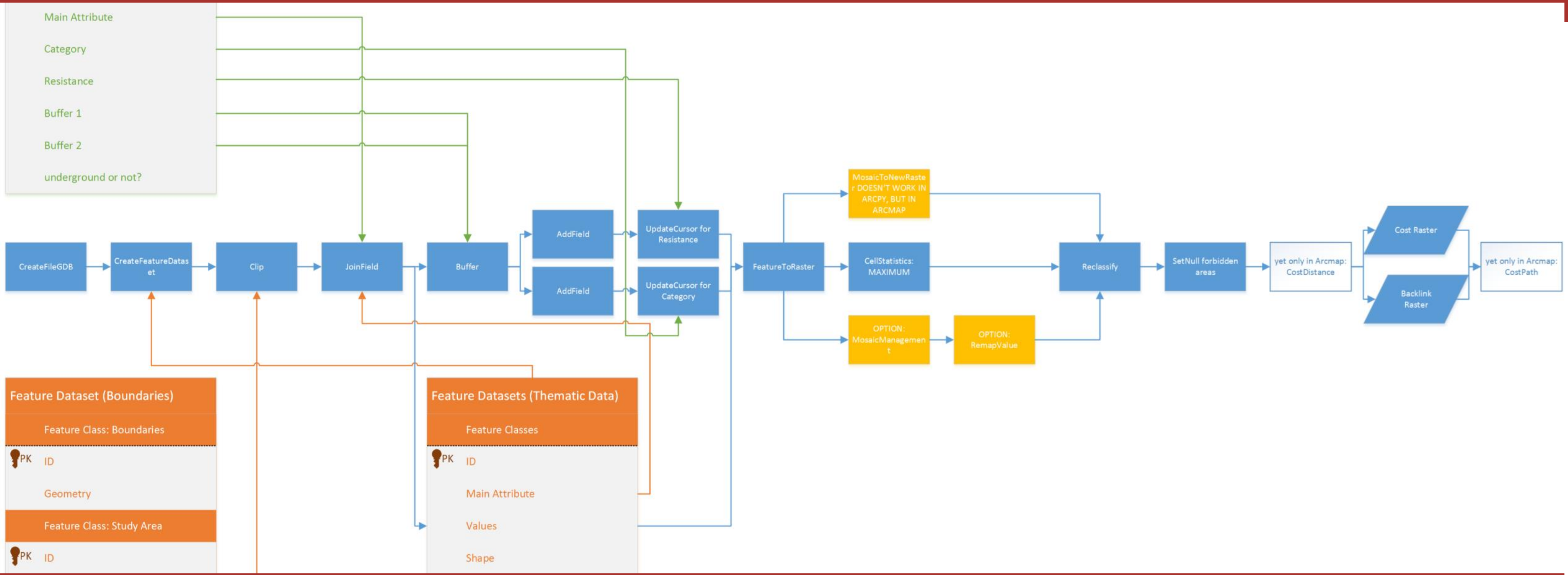


Quelle: Titelblatt «Bewertungsschema für Übertragungsleitungen», BFE (2013)

Result: Definition of a Model to Preprocess and to Structure Data Using 4 Dimensions and 14 Factors

Dimension	Factors
Environment protection	Ecosystems supporting biodiversity Protective habitats Waters protected by water act
Landscape conservation	Landscapes protected by law Conservation of agragricultural 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
Natural constraints	Natural hazards Slope Building ground

- Define avoidance areas
- Define cell resolution
- Define the study area and how to get to the planning area
- Avoid thematic overlapping (Autocorrelation)
- Consider different legal prerequisities
- Clarify how the features should be modeled (e.g., point and line features do not have an areal extension)
- Carify thresholdswith experts
- Elaborate a method how to handle different detail level



Algorithm Development

Approaches and Results of Workpackage 2

Algorithm Development = Workpackage 2

WP1

WP2

- Develop an algorithm for routing, pylon positioning, and cost estimation

WP3

WP4

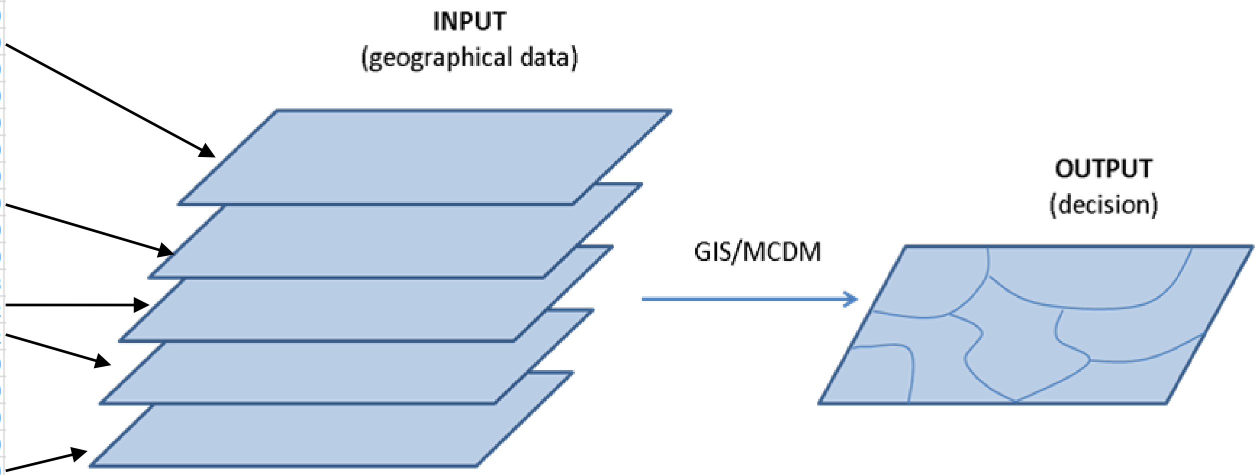
- Steps
  - Use the funnel approach to model study area → planning area → corridor → path → pylon position
  - Combine MCDA weighting with least cost path algorithm

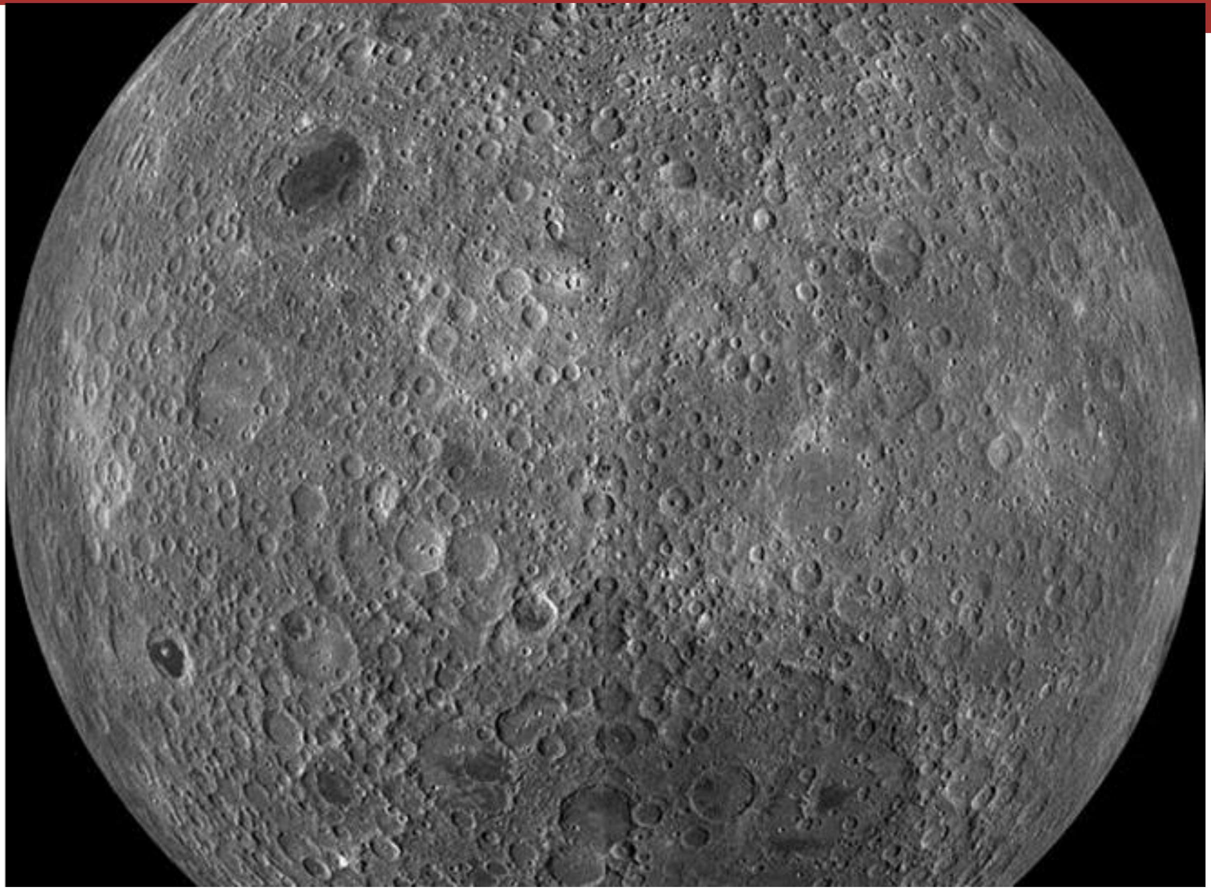
→Conduct a sensitivity analysis to test the factor's influence

→Develop optimization methods

Multi-Criteria Decision Analysis (MCDA): The Weighting Defines 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



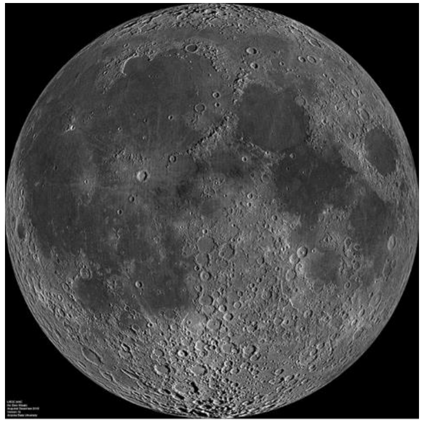


MCDA: The Near Side of the Moon

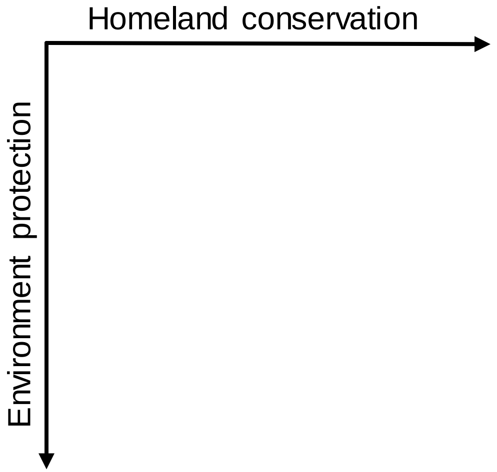
What the User Can Adapt

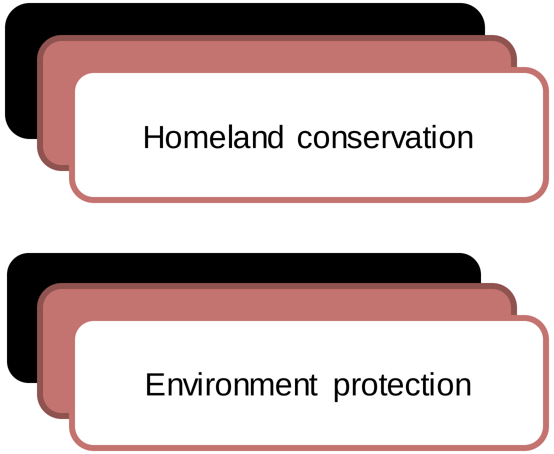
Method: MCDA – According to the Moon, one MCDA Is Visible, whereas the other Is not

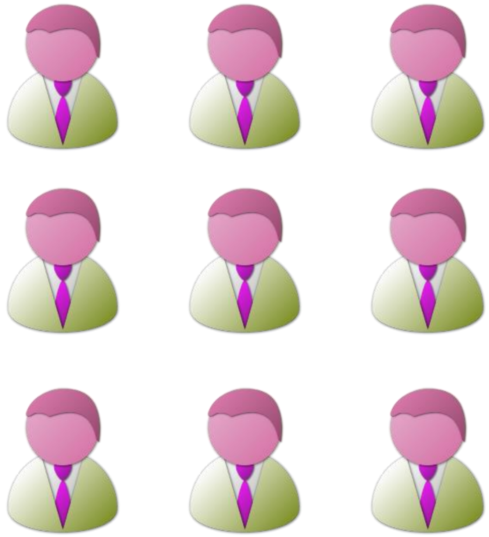
- Visible to the user:
  - Category weight in one separate weighting table
  - Layer weight for each attribute defined in the table
  - 9 pre-defined weight settings based on the scenarios
- The user handles the data following a guideline:
  - Explaining how to set up the main attribute a table
  - Explaining how data should be prepared

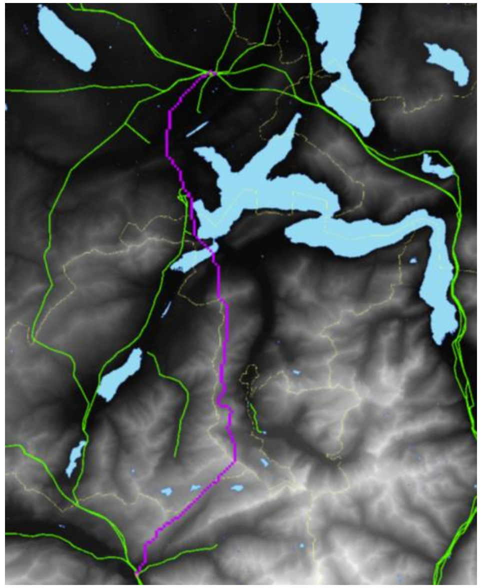


Method: MCDA – In the Beginning, the User Chooses 1 of 9 Pre-Defined Scenarios









2 dimensions

3 possibilities

9 pre-defined scenarios

1 output per scenario

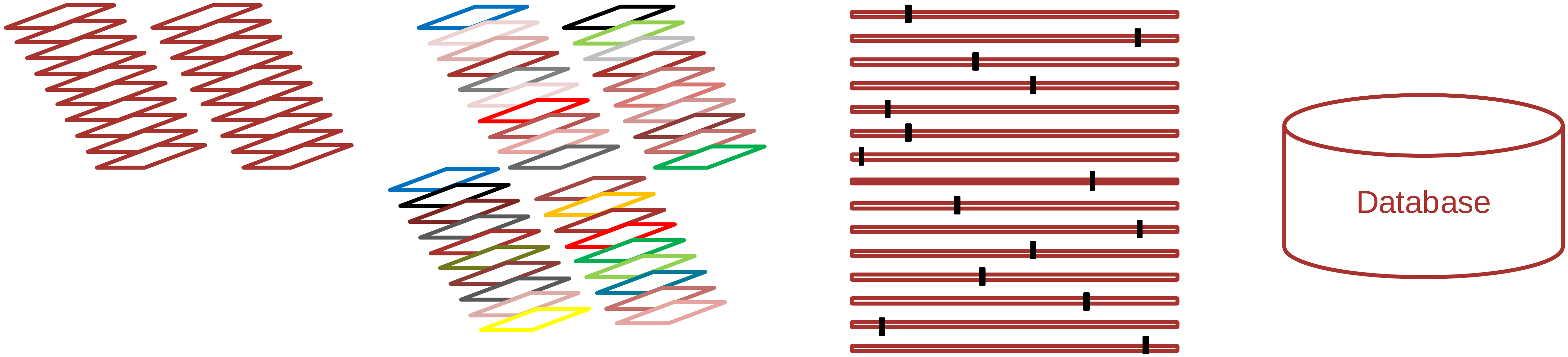
Geodatabase

immediately

Method: MCDA – In the Beginning, the User Chooses 1 of 9 Pre-Defined Scenarios

		Homeland conservation		
		not important	moderately important	very important
Environment protection	not important	**Homo oeconomicus**	**Opportunist**	**Aesthete**
	moderately	**Agronomist**	**Moderate**	**Conservator**
	very important	**Rationalist**	**Ecologist**	**Sustainable**

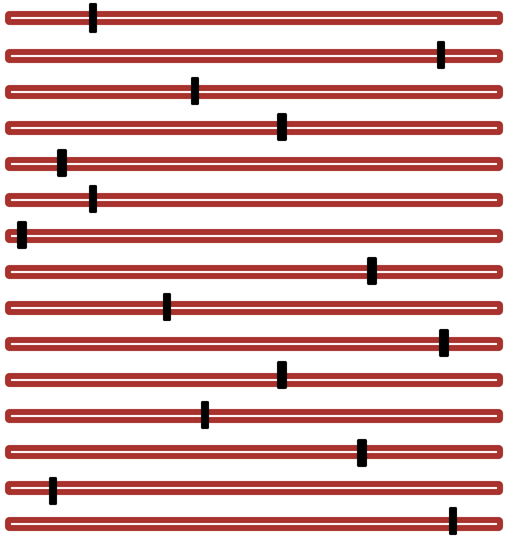
Method: MCDA – First, Preprocess the Data



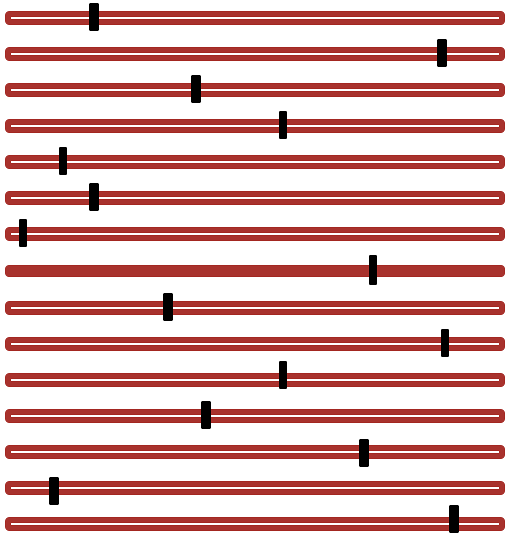
1. Take the files and split them based on their main attribute.
2. Reduce them to 14 factors and store them in a database.

Method: MCDA – Next, the Dimensions and the Factors Can Be Weighted

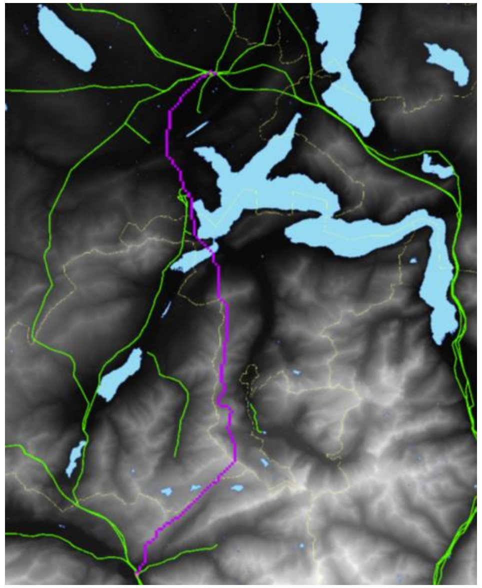
4 dimensions to weight



14 factors to weight

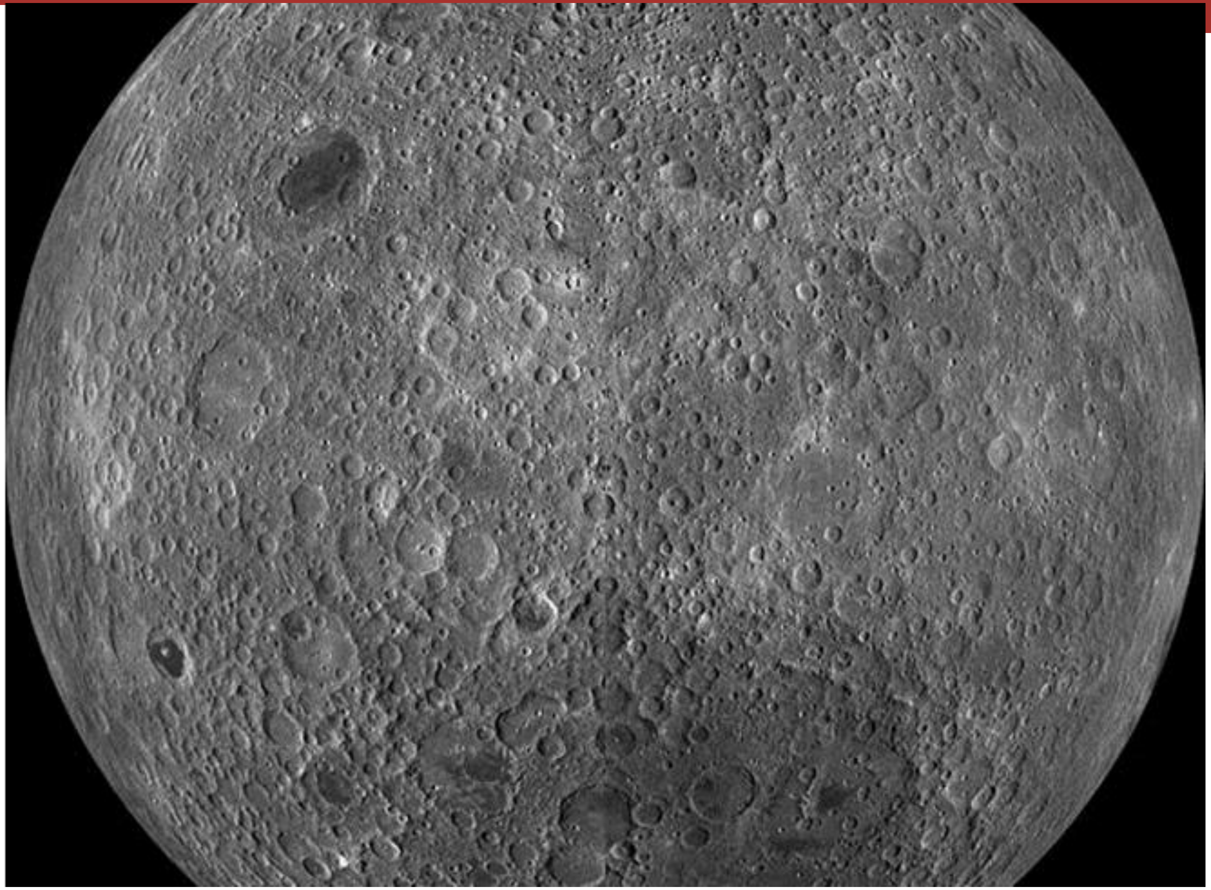


define the factor's resistance



1 output

a few minutes



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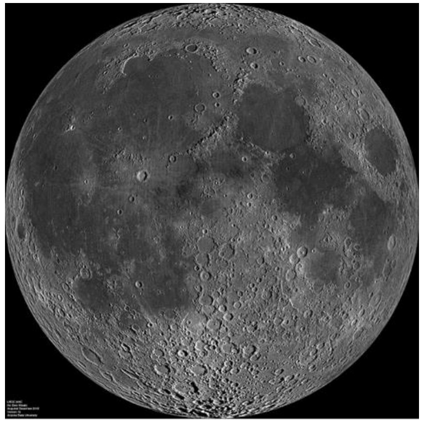
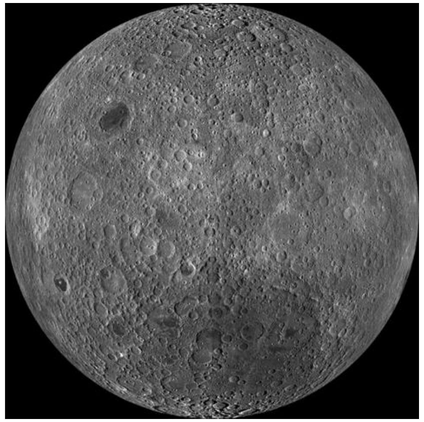


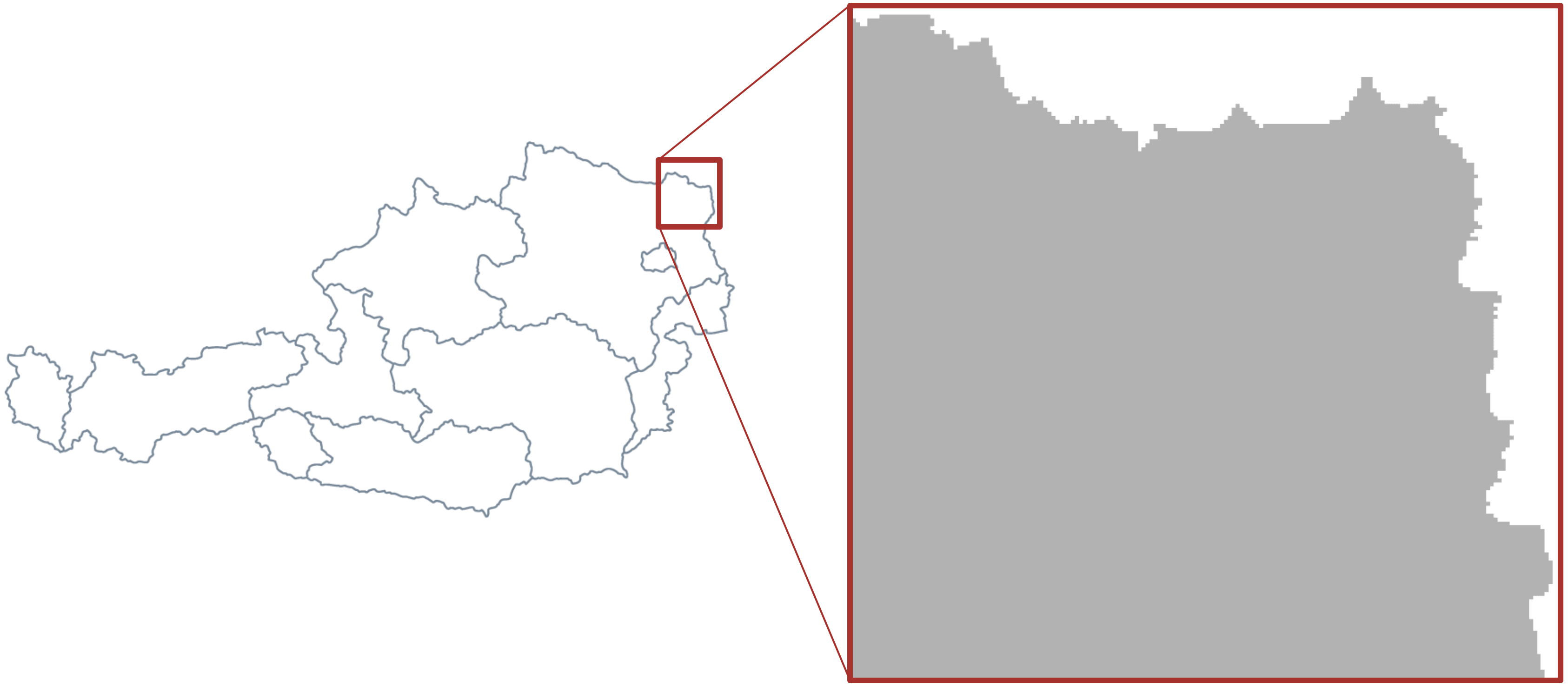
- Hidden from the user:
  - Variances in weighting (e.g., a weight sum of 99.9986%)
  - Variances concerning the used factors (start/end point, proximity factors, inverse distance weights, distance radii, point densities, decreasing impact while overlapping, conficence interval, etc.)
  - Variables that determine the model’s robustness.
  - Technical variables that cannot be changed (physics, DEM)
  - Values and buffer slopes set by experts



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



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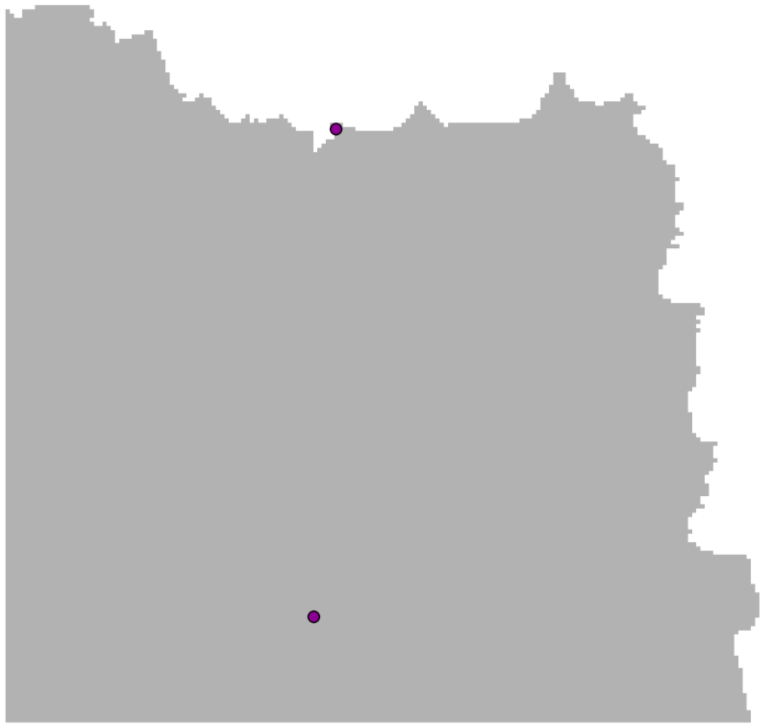

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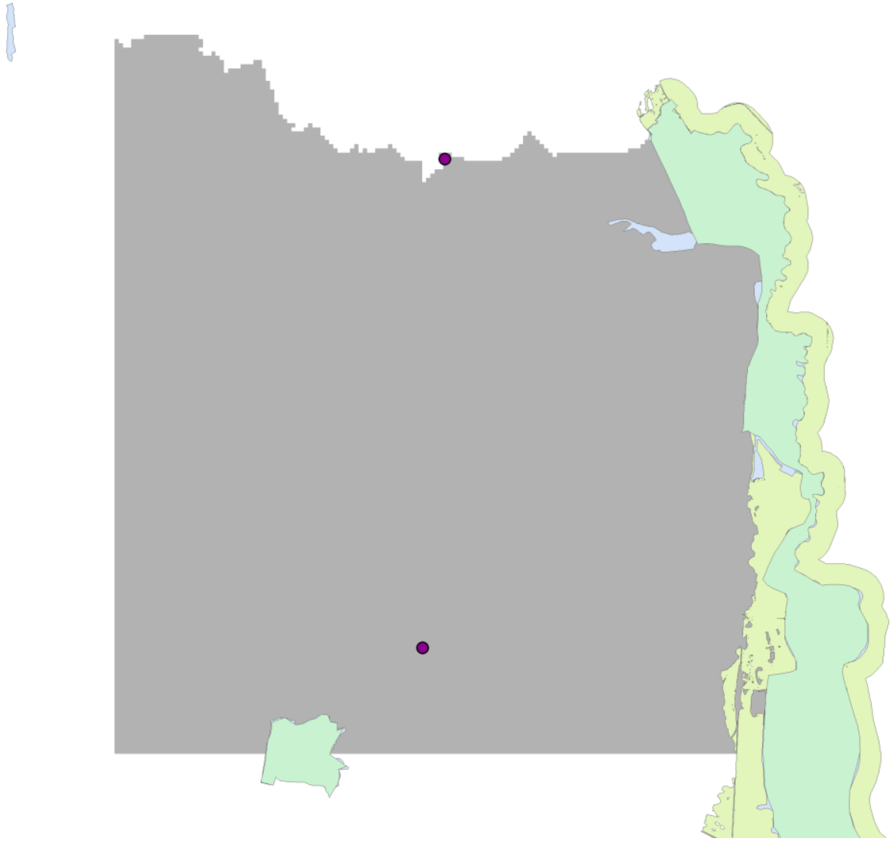

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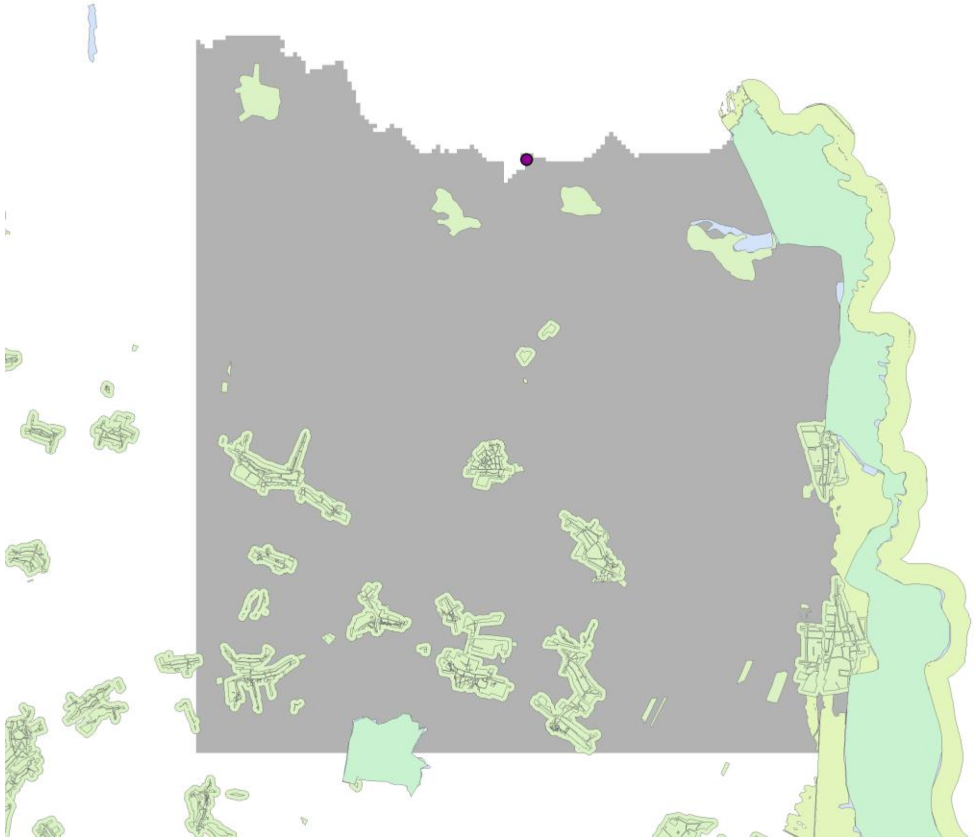

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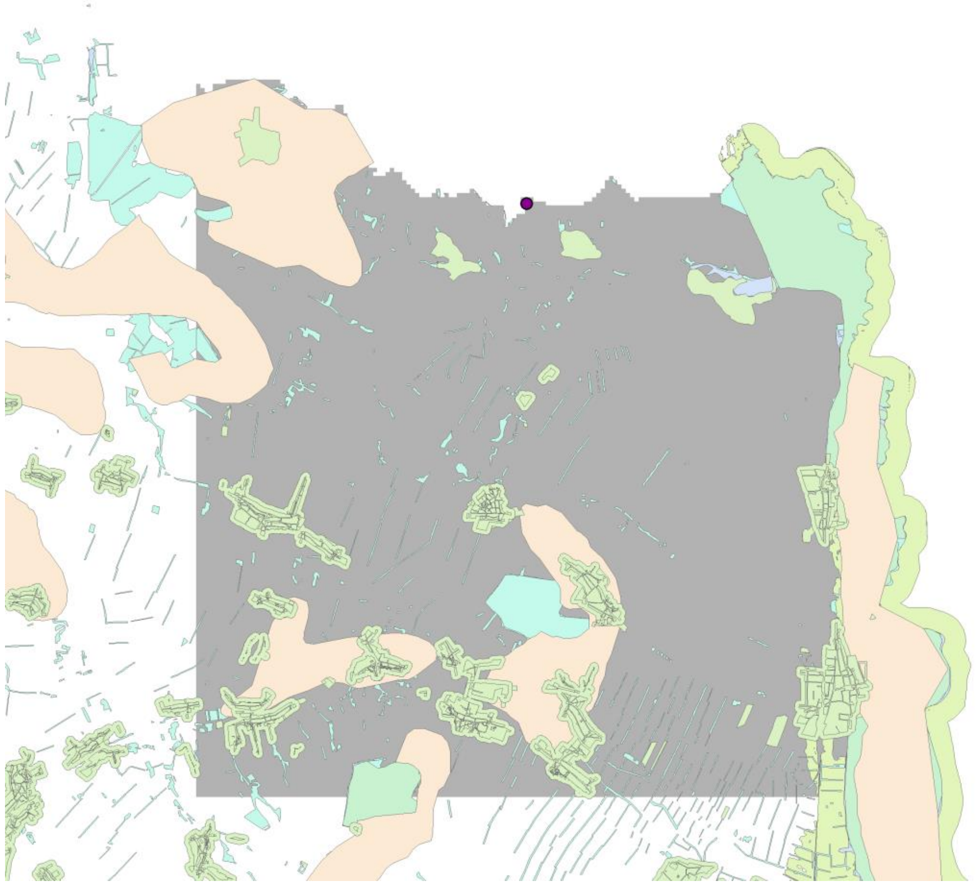

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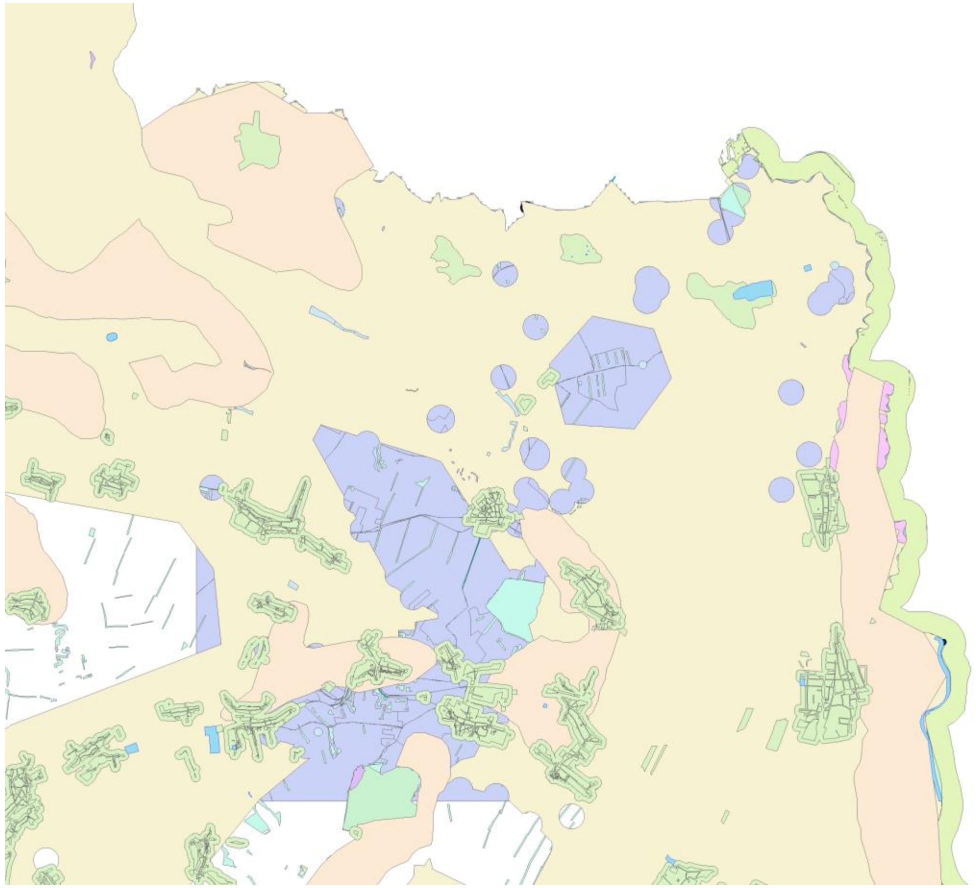

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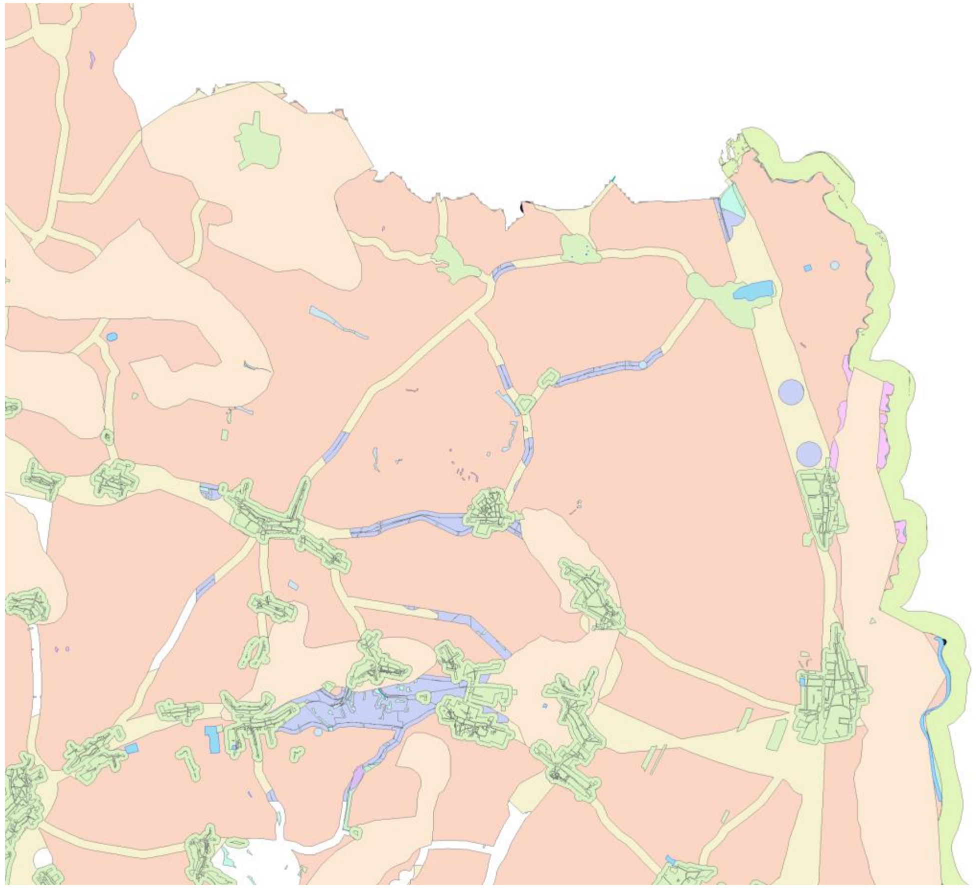

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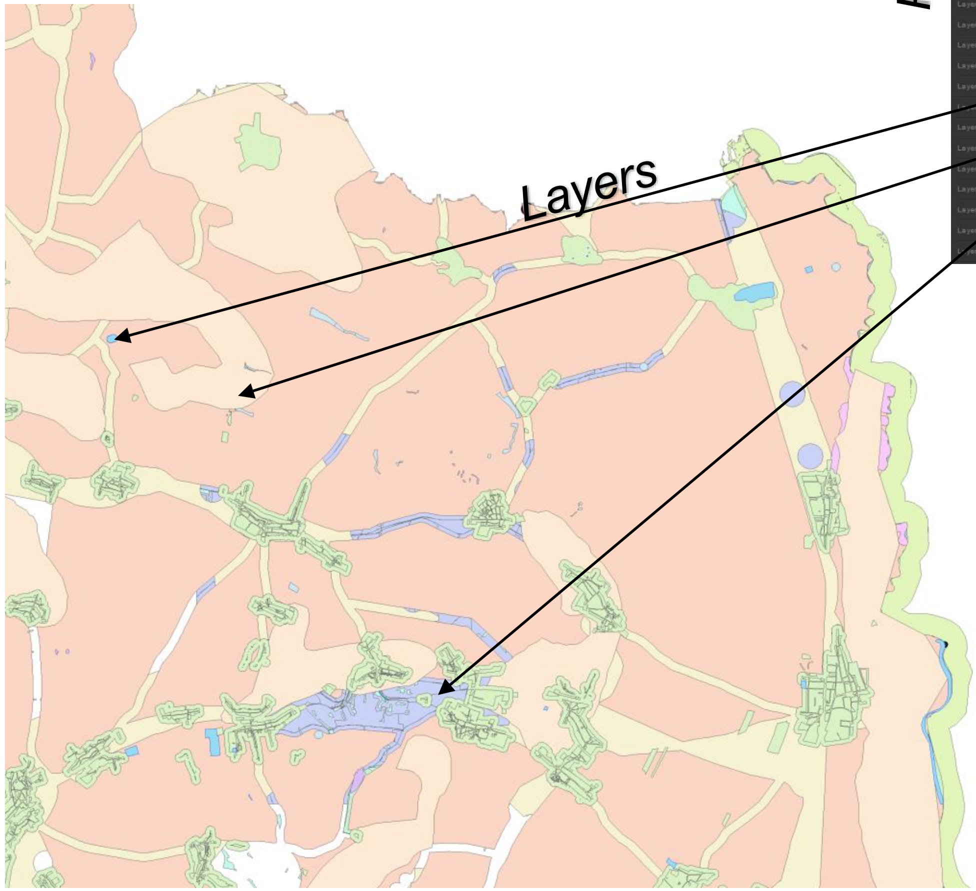
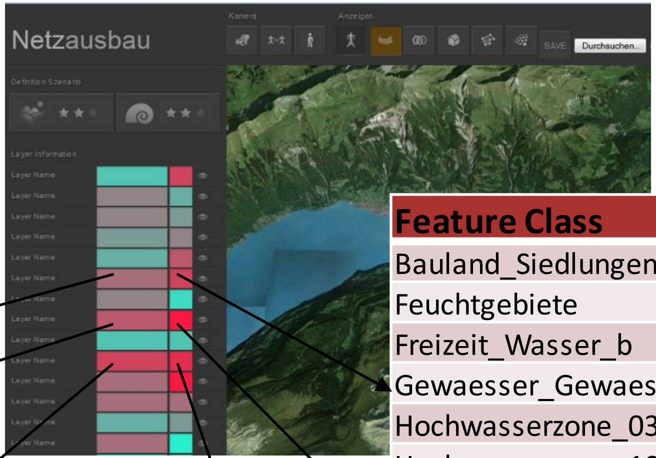
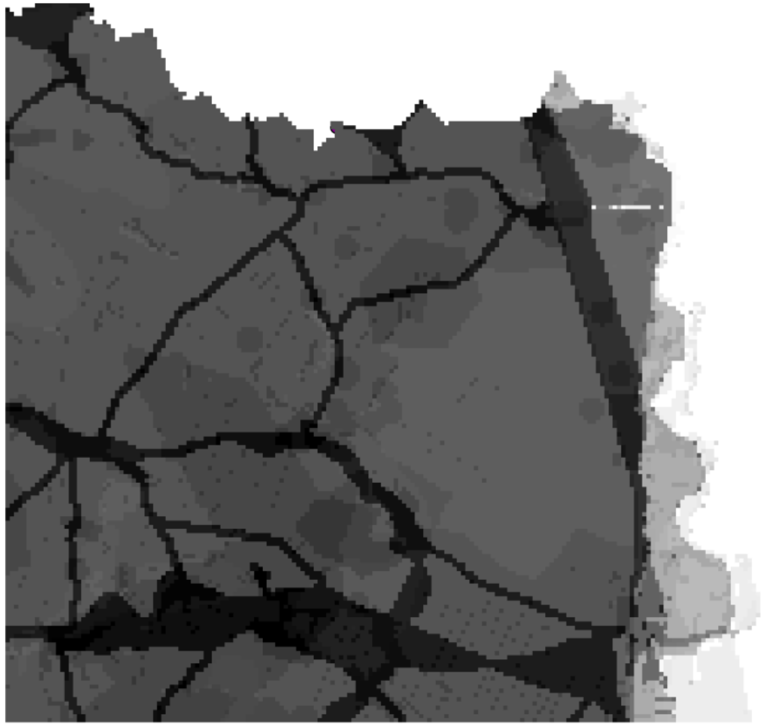




Weight Table

Feature Class	Restistance	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



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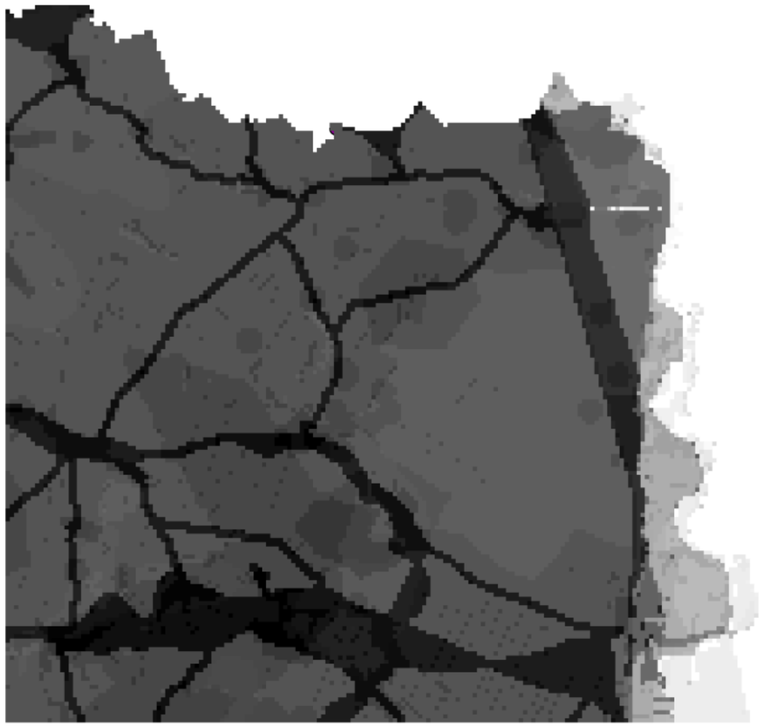
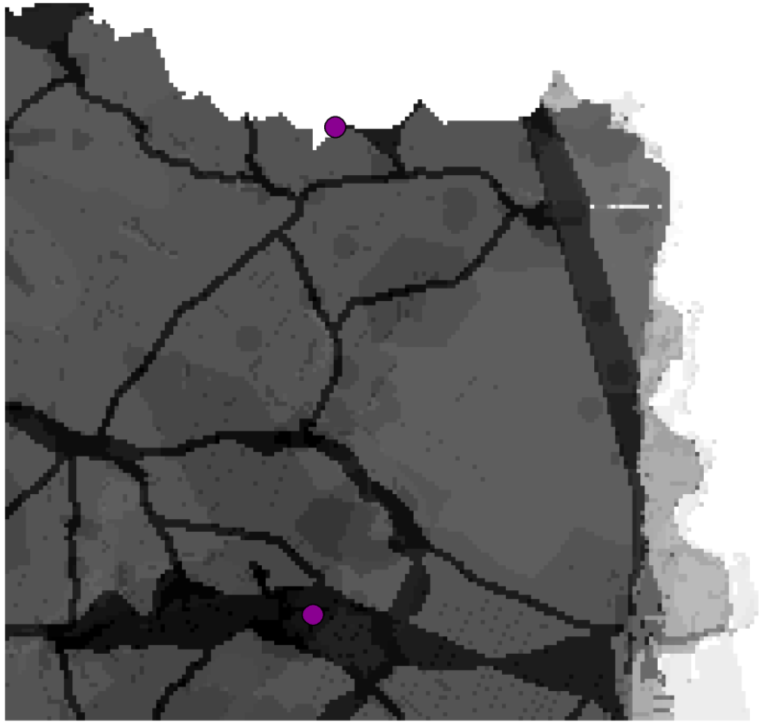


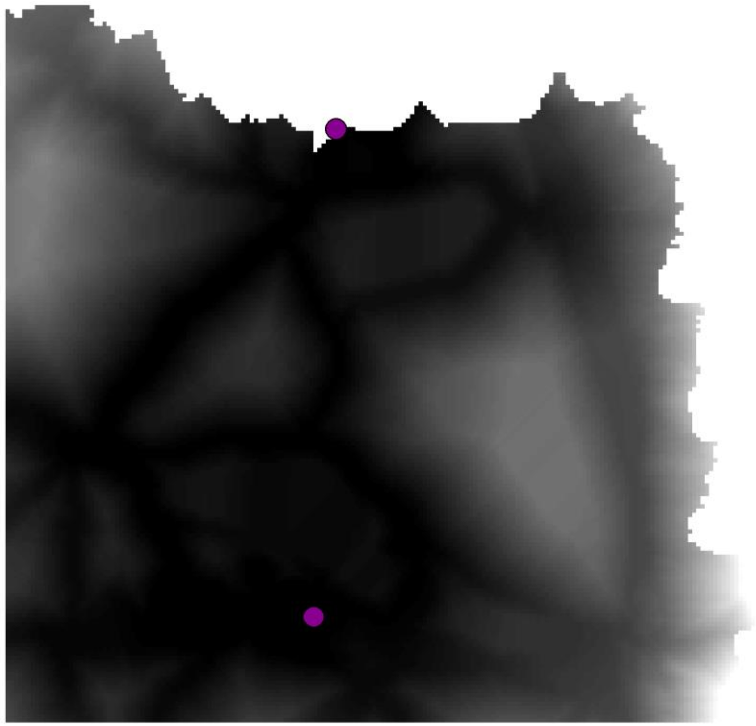
Cost Surface

How a Cost Surface Is Built



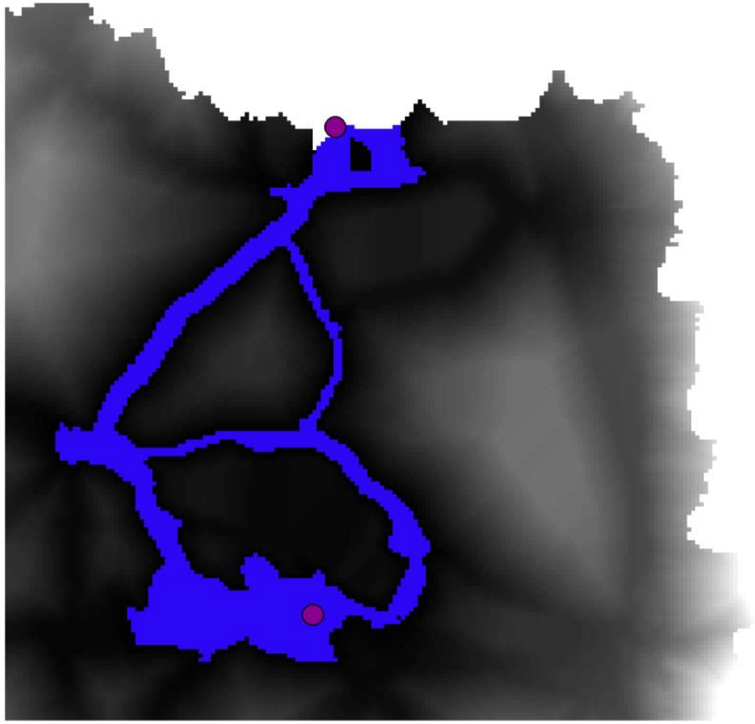
Cost Surface

How a Cost Surface Is Built



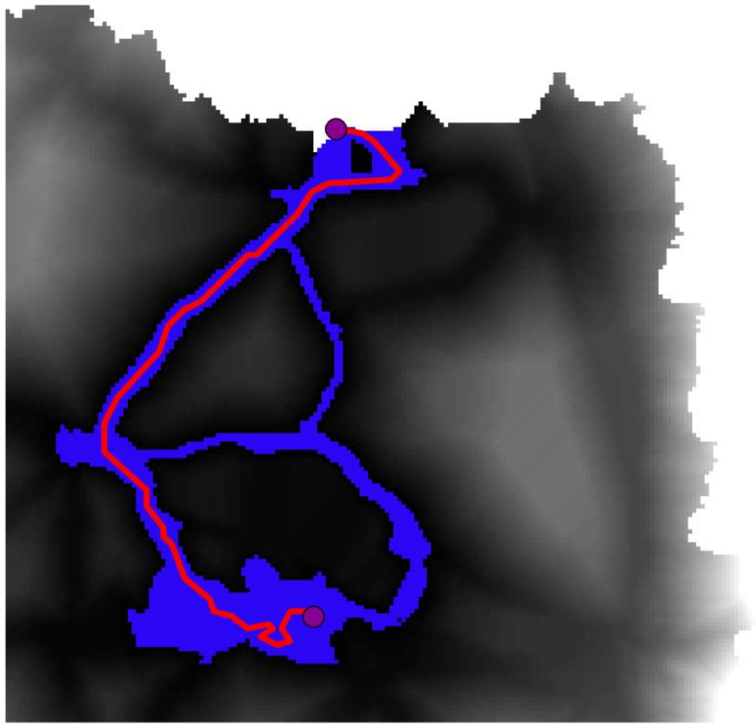
Global Cost Surface

How a Cost Surface Is Built



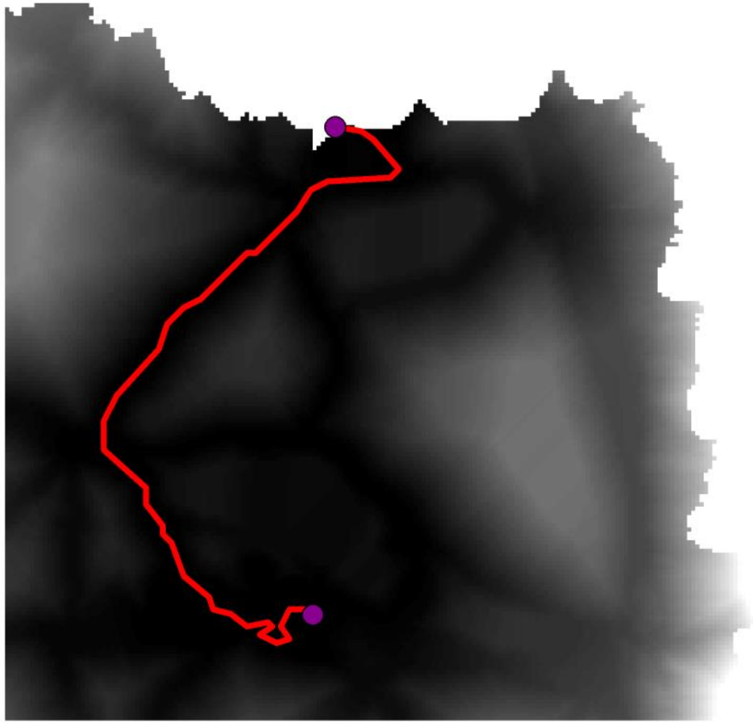
Global Cost Surface + Corridor

How a Cost Surface Is Built

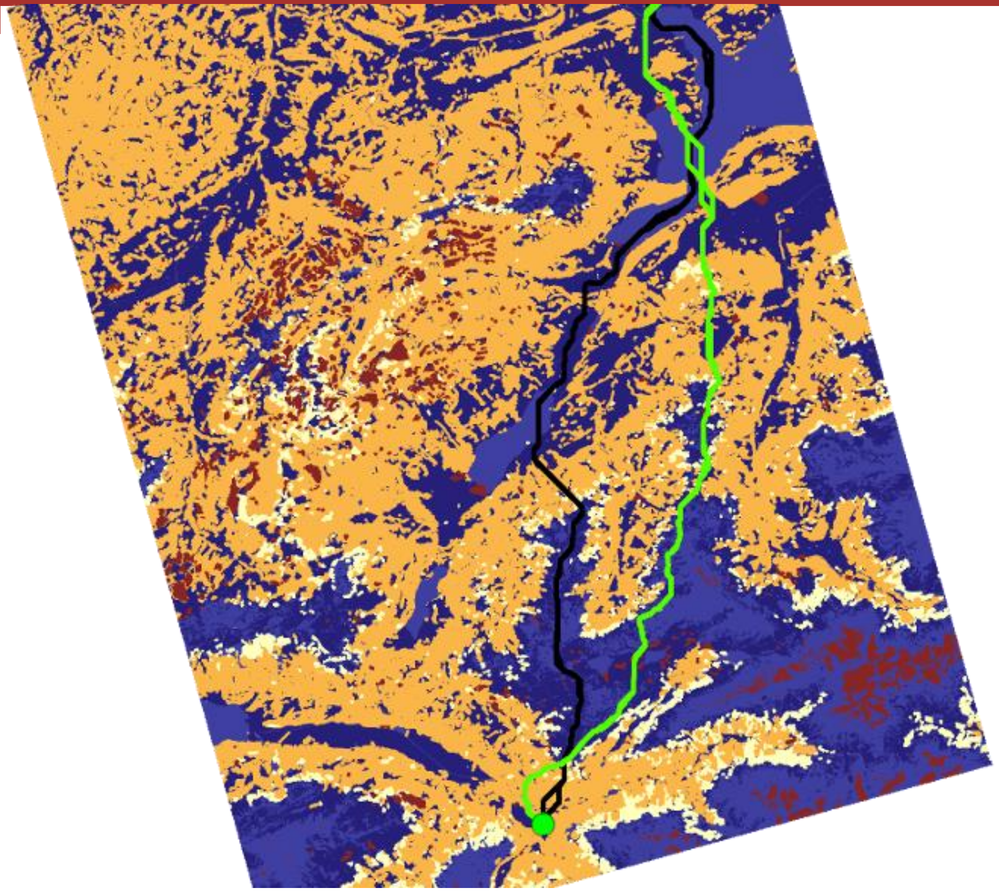


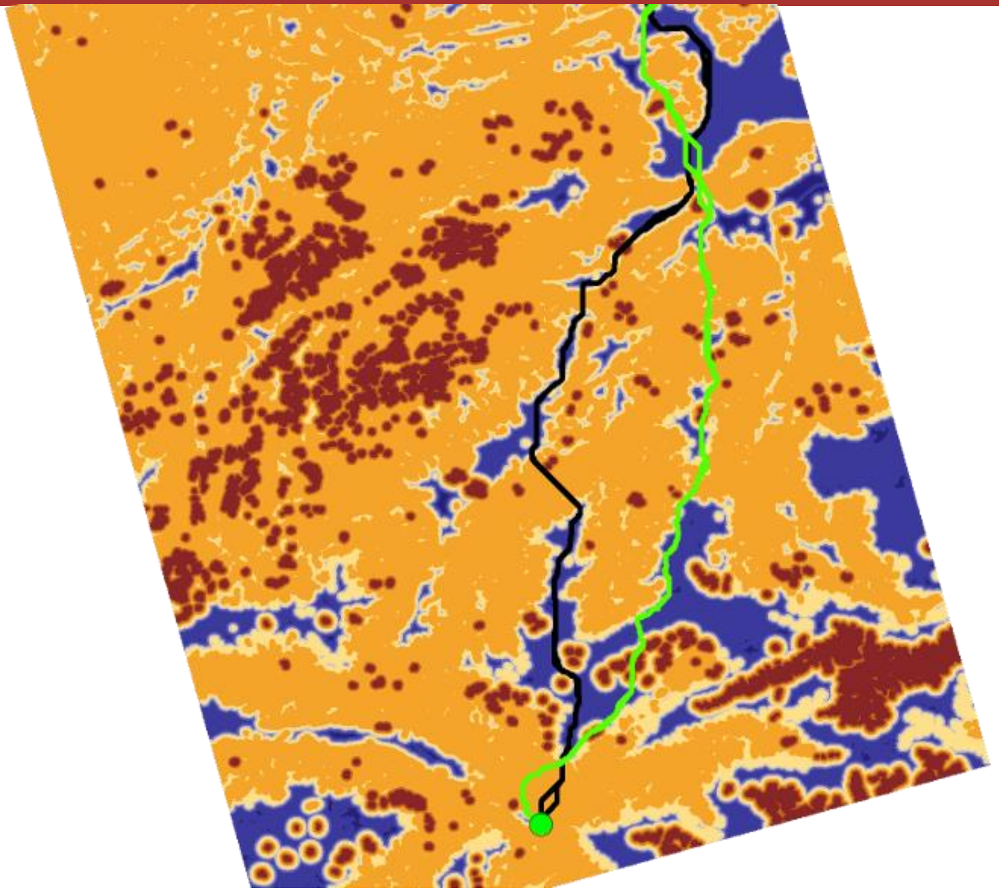
Global Cost Surface + Corridor + Path

How a Cost Surface Is Built



Global Cost Surface + Path





Results of the Algorithm Development

Approaches and Results of Workpackage 2

Result: MCDA & Least Cost Path – 12 Limitations of the LCP Algorithm

Advantages and Limitations of the Least Cost Path Algorithm for Planning Transmission Lines

Keywords

Shortest Path, Least Cost Path, Least Cost Corridor, Multi-Criteria Decision Analysis, GIS, GIScience.

Abstract

As for linear infrastructure in general, the planning of transmission lines makes use of Geographic Information Systems, including algorithms capable to determine an ideal path between two points. Therefore, two methods are commonly combined with each other in order to find a solution suitable for all involved stakeholders: the Least Cost Path algorithm, which determines a path of lowest friction, and Multi-Criteria Decision Analysis, which structures decision-making in order to avoid subjectivity. Although both methods are well-established in the transmission line planning process, their use still leads to some inconsistencies. In this paper, we refer to previous transmission line planning projects that made use of both methods. Twelve inconsistencies are identified based on the raster representation, Dijkstra's algorithm, and concerning practical limitations. We then provide solutions for these inconsistencies found in the literature and through our own work in this field.

Schito and Raubal (2015, submitted)

- Constraints based on the raster representation
  1. Solutions are bound on a lattice which is non-realistic
  2. Distances are discretized on isotropic surfaces
  3. Mostly, only the Queen's lattice is considered
  4. Cell size affects the result
- Constraints based on Dijkstra's algorithm
  5. Homogenous friction causes zig-zag paths
  6. Solutions tend to approximate class borders
  7. Only one scenario (=one cost surface) can be considered at once
  8. Numerical constraints (min/max distances) are entailed
  9. Varying types of costs cannot be considered
- Practical limitations
  10. Time-dependent costs were seldom considered in the past
  11. The weightings of the MCDA factors is highly subjective
  12. LCP reduces solutions to one pixel, neglecting other solutions

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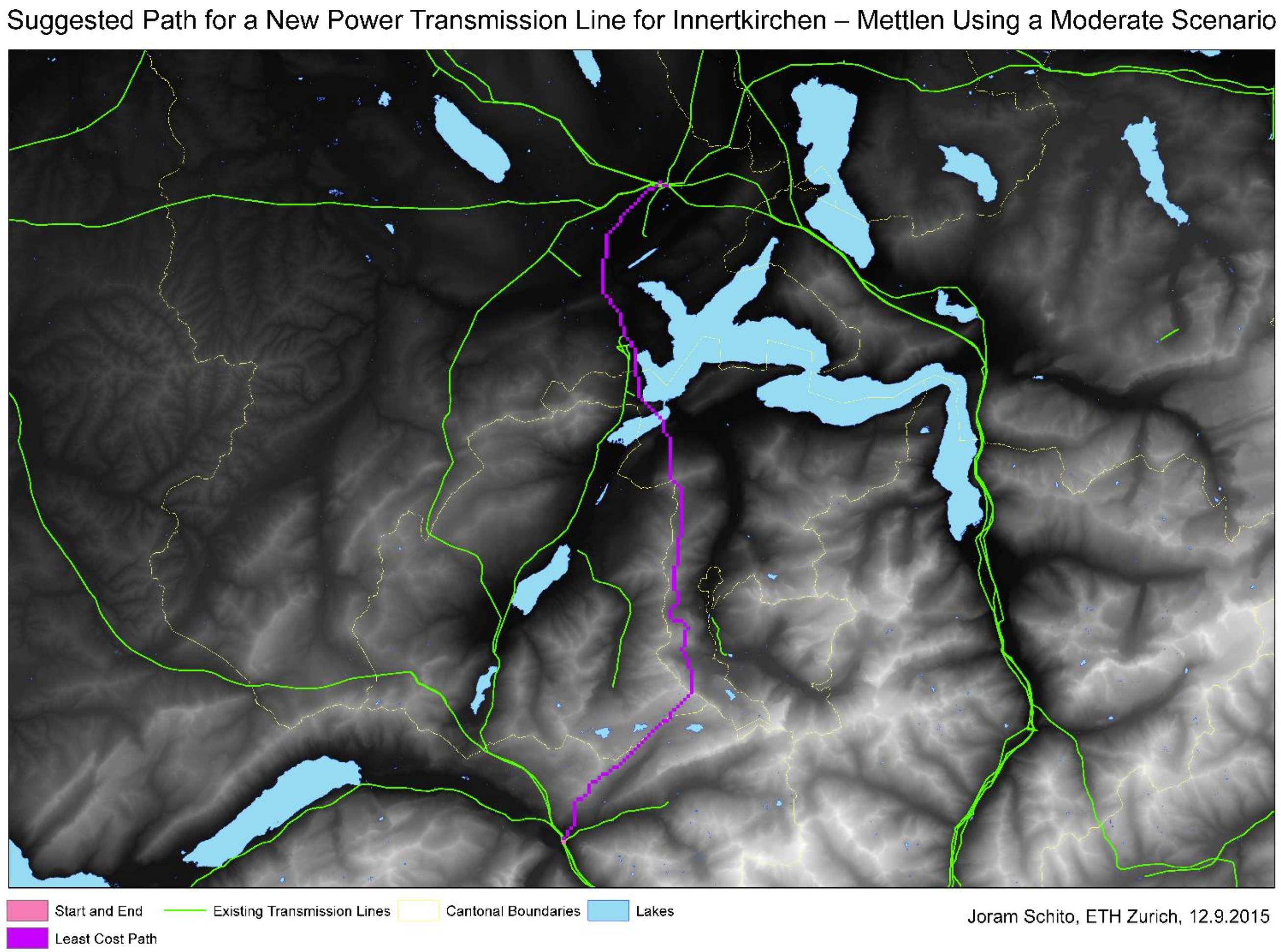
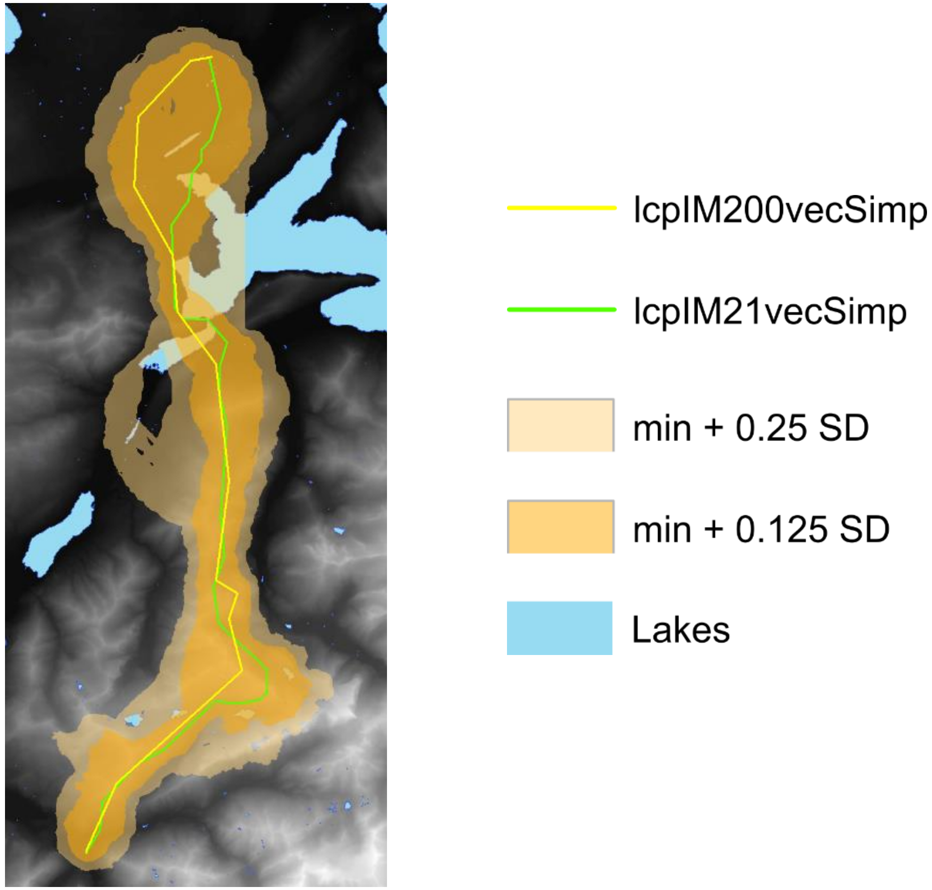
Result: The LCP/LCC Algorithm Works




```
    arcpy.CreateFeatureDatas
    arcpy.CreateFeatureDatas


def changeProjection(): #NOT
    #the projection is chang
    #IMPORTANT: ALWAYS TRANS
    fc_projected = os.path.j
    arcpy.Project_management
    arcpy.Delete_management(
    fc_preprocessed = fc_pro


def clip(fd, fc):
    clip_in_fc = os.path.joi
    clip_features = os.path.
    fc_clipped = os.path.joi
    clip_cluster_tolerance =
    arcpy.Clip_analysis(clip

    #exception: if FC is voi
    rowsInClippedFC = arcpy.
    if rowsInClippedFC == "0
        arcpy.Delete_manager
    else:
        return fc_clipped


def joinData(fd, fc, fc_prep
    #creates a new field wit
    arcpy.AddField_managemen
    cursor = arcpy.UpdateCur
    category = fd
    for row in cursor:
```

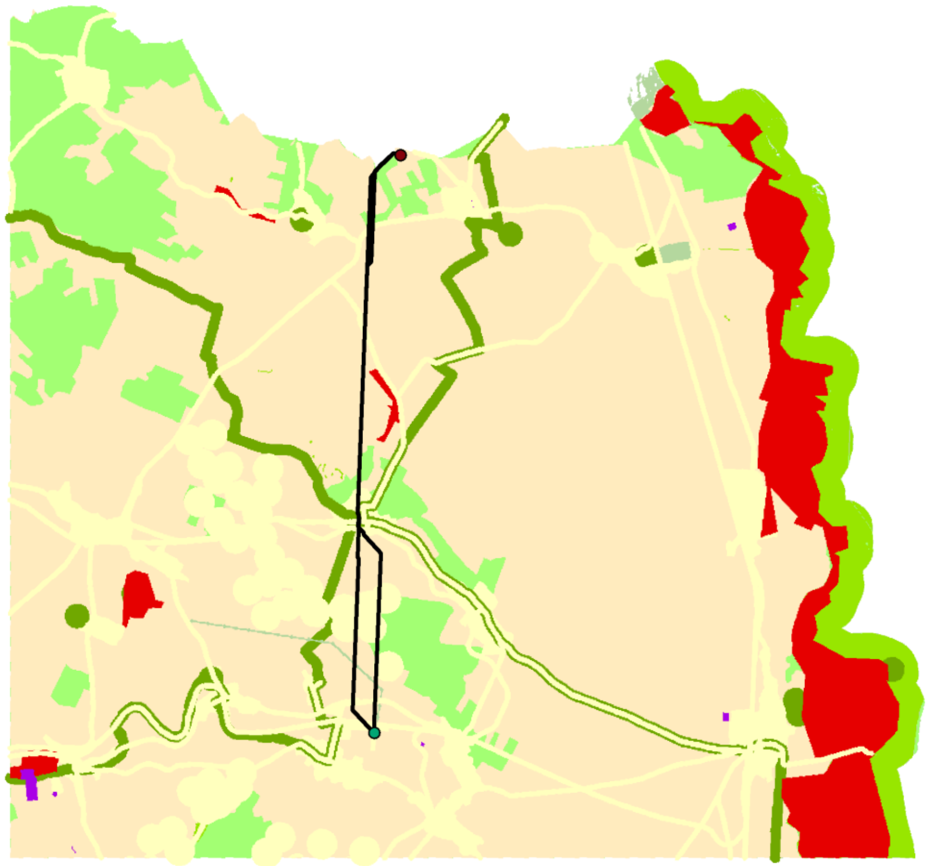
Result: The Processing Resolution Matters

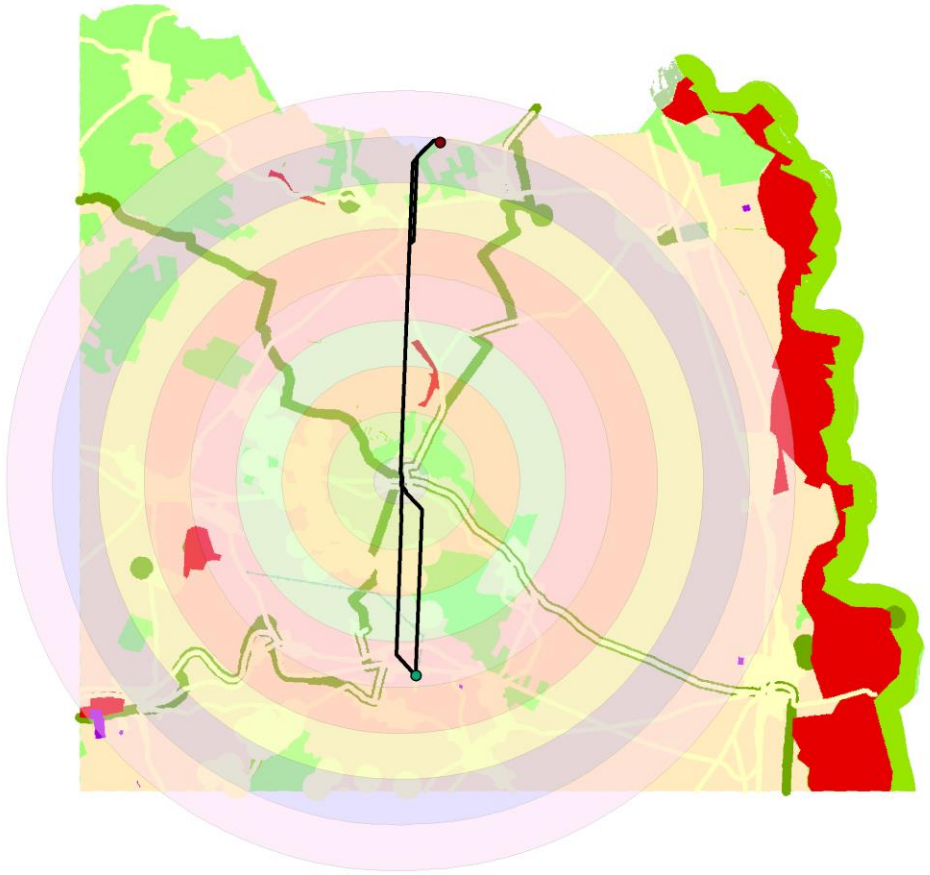


- Yellow line: cost raster processed on a 250 m resolution
- Green line: cost raster processed on a 20 m resolution

- Both lines lie within the corridor of 0.125 SD tolerance, albeit using a different resolution.
- Could it be a possible solution to work with different resolutions precisely because the path must be straightened anyway?

Result: Sharply Delimited Features Deteriorate the Result's Reliability





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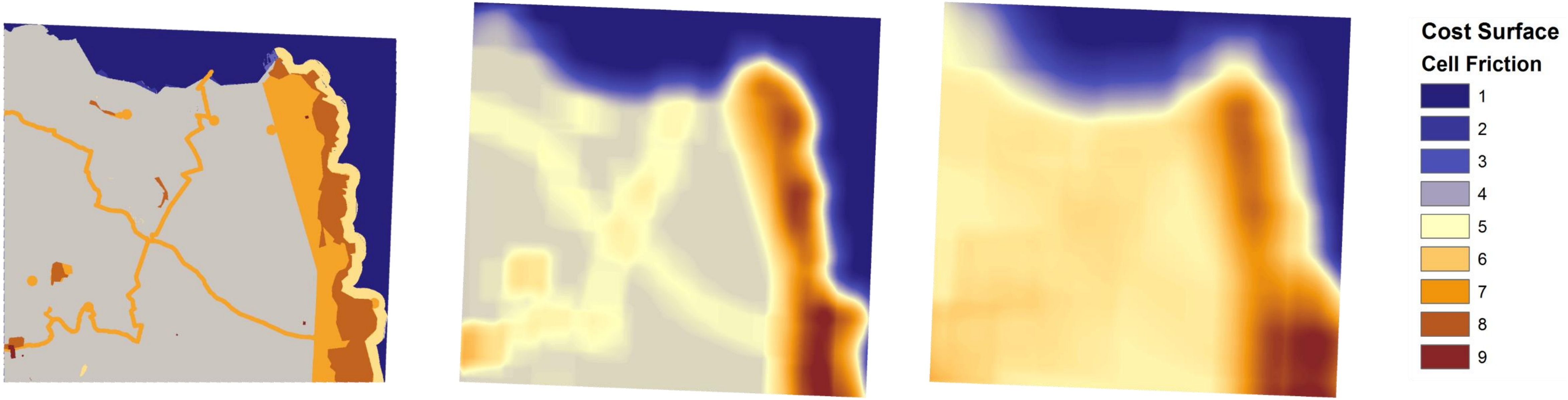
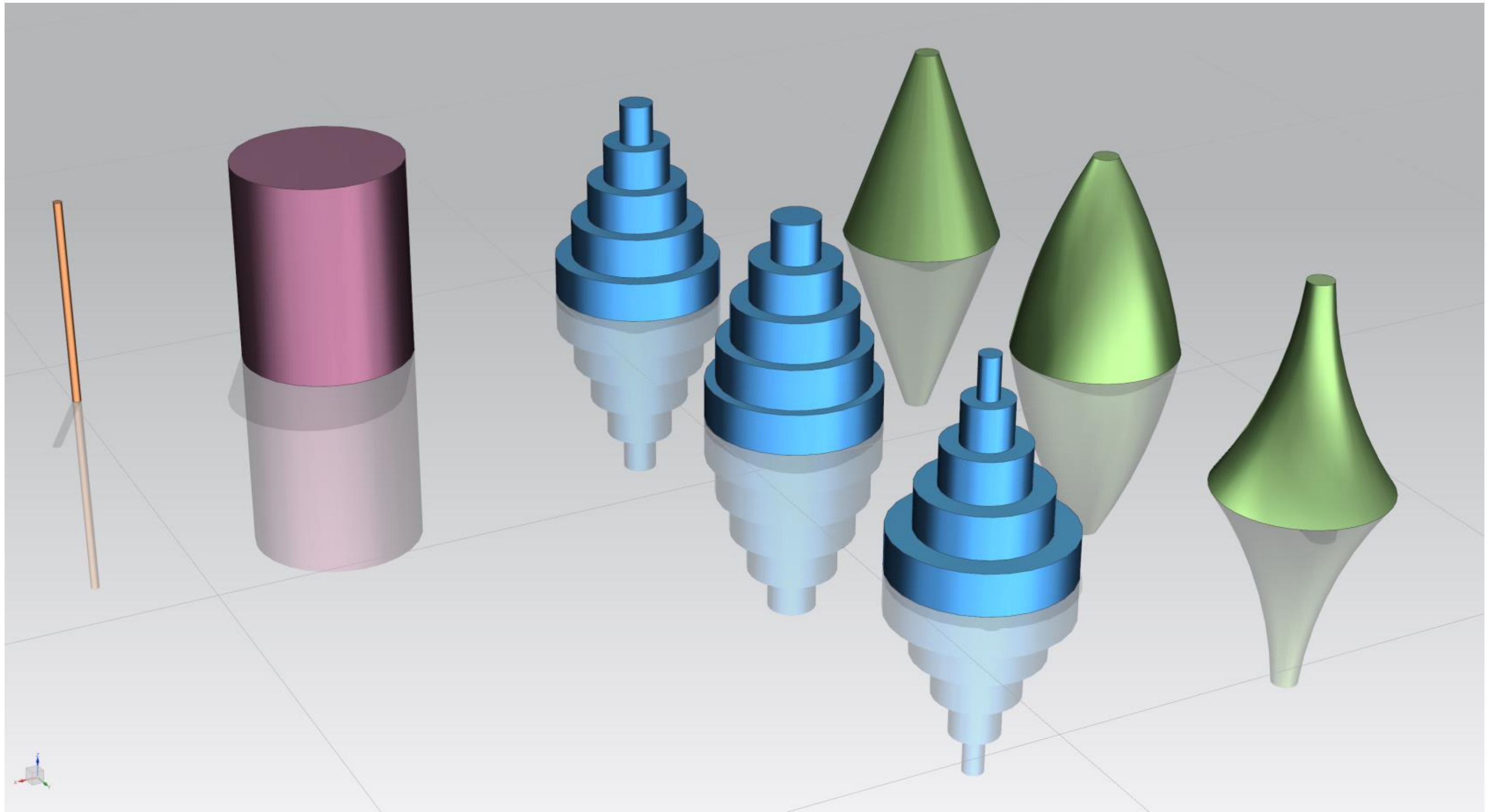
Result: Fuzzy Cost Surface Might Represent Protection Areas more Realistically

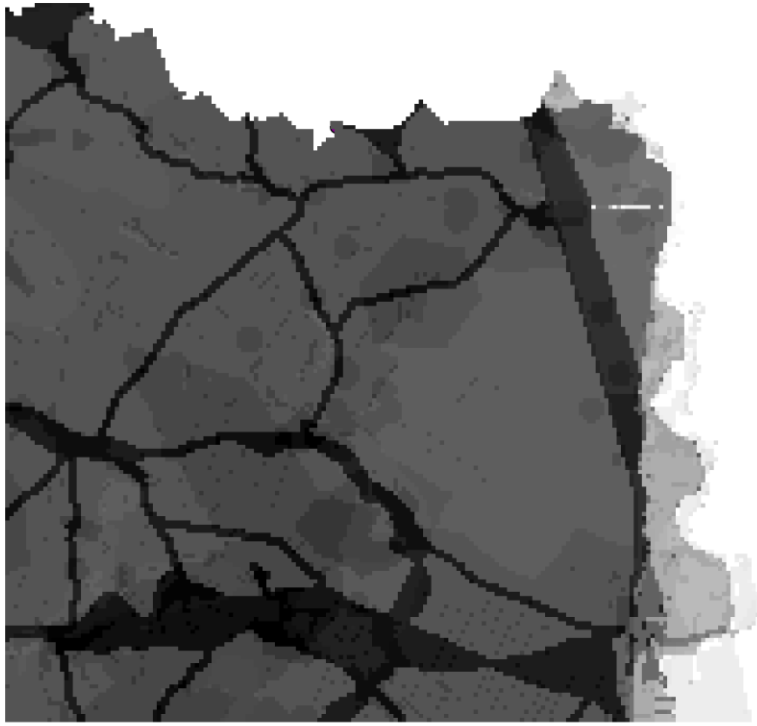


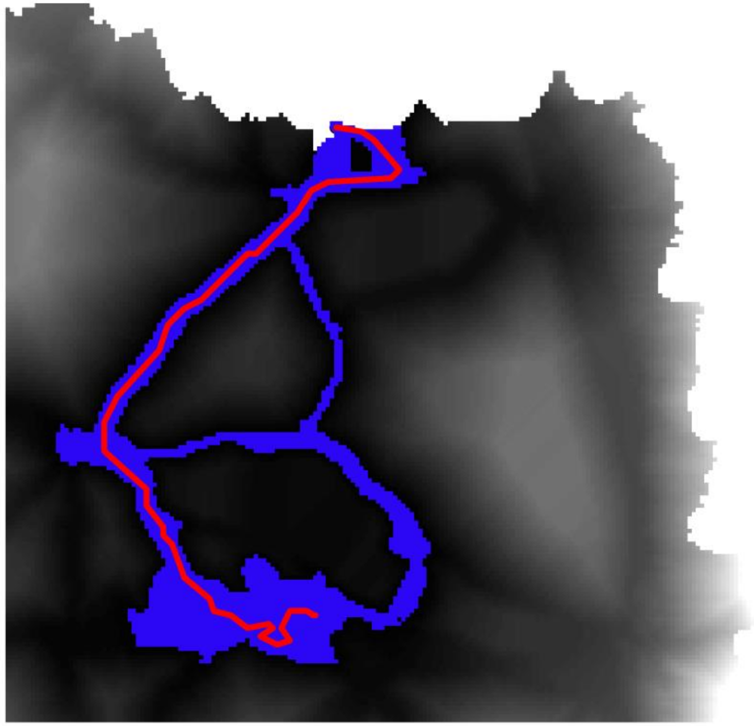
a) b) c)

Result: According to Tobler's First Law, Continuous Buffering Is Best to Use



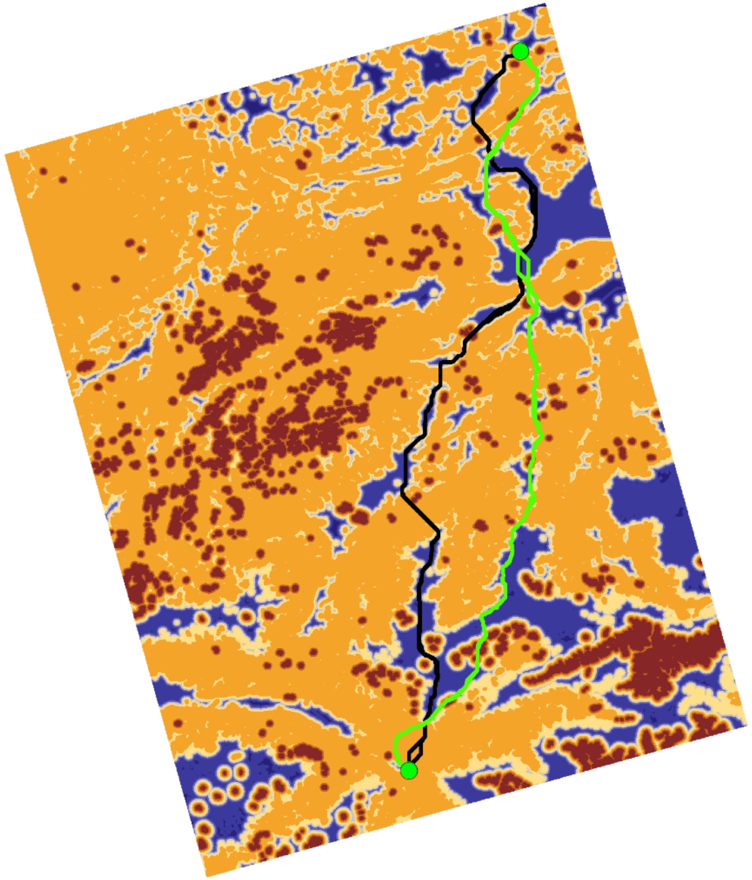
From the Global Cost Surface to the 0.125SD Least Cost Corridor to the Least Cost Path



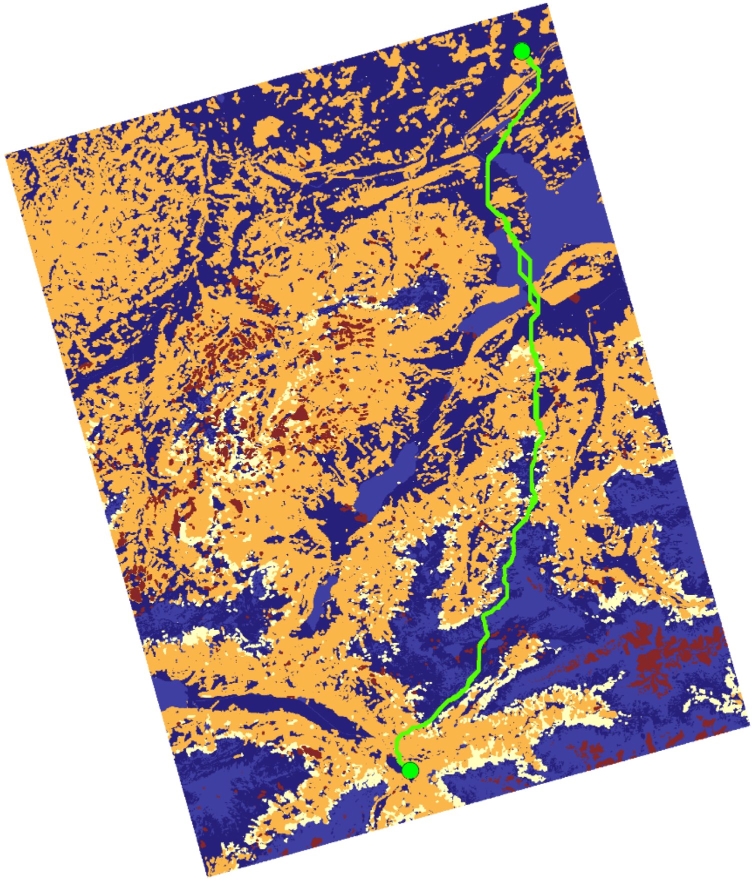


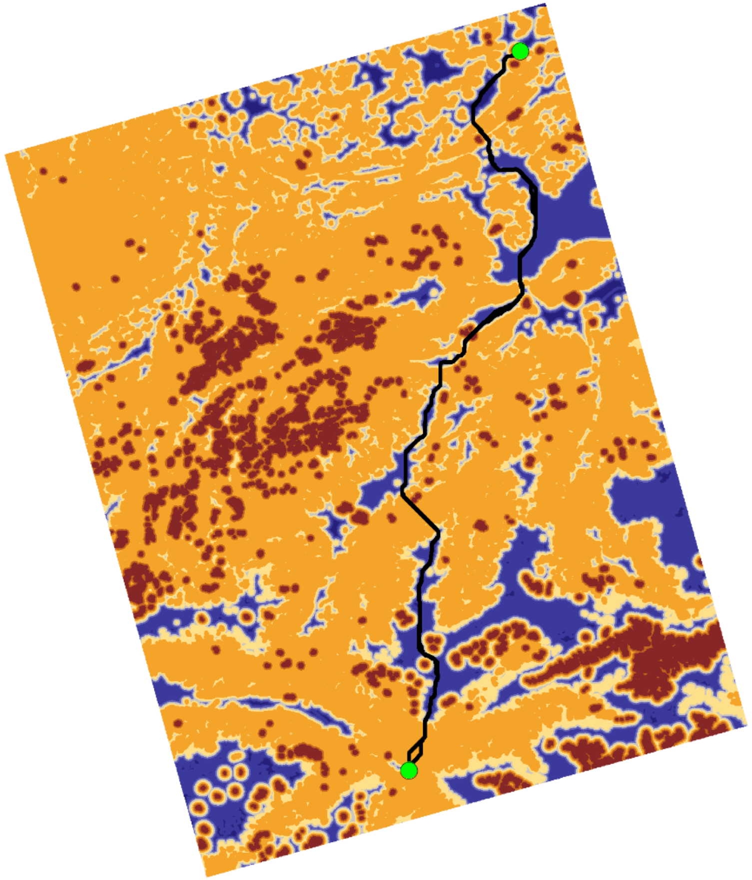
Result: Avoiding Proximity is Beneficial for the Route

- Because in a high-resolution raster no generalization has been done, the LCP algorithm ignores if the density of protection areas within a region is generally high or not.
- Proximity correction may find another route in less protected areas, even if costs are higher.
- Generally, routes through lakes seem to ba suitable because of low costs.



Demostration



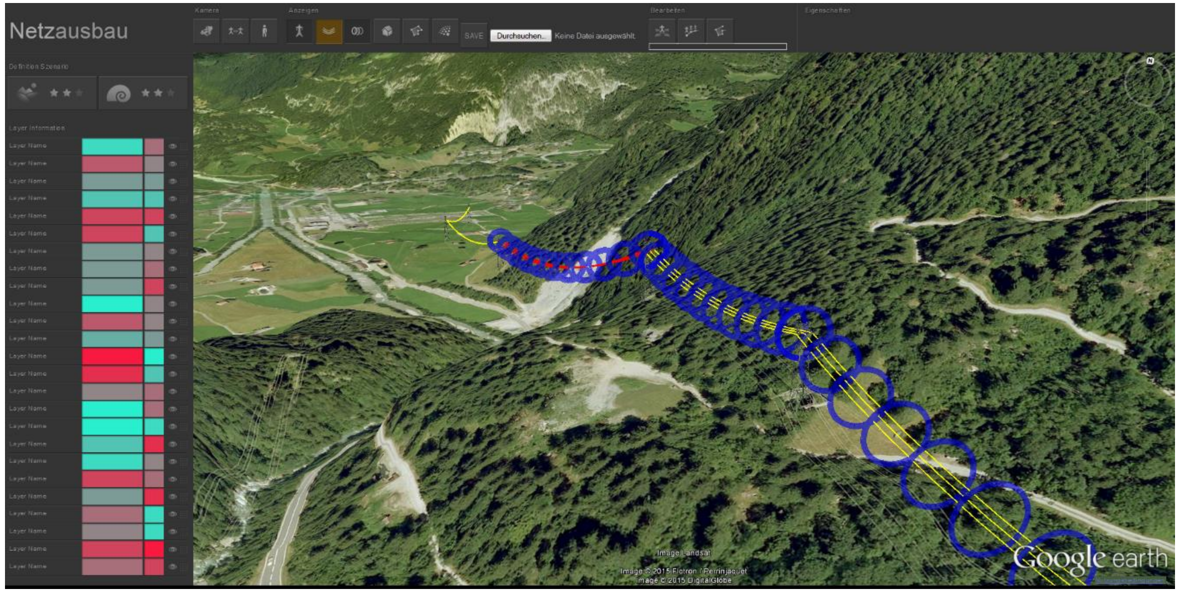


Future Outlook

On WP3 & WP4

February / March 2016: Integrate the Algorithm in the 3D DSS Platform

- Develop a script that communicates between the platform and the algorithm.
- Set up a server solution for the algorithm.
- Make the algorithm more generic.
- Improve the computing time.



- Conduct **usability studies** of the prototype.

Master Thesis starting in March 2016

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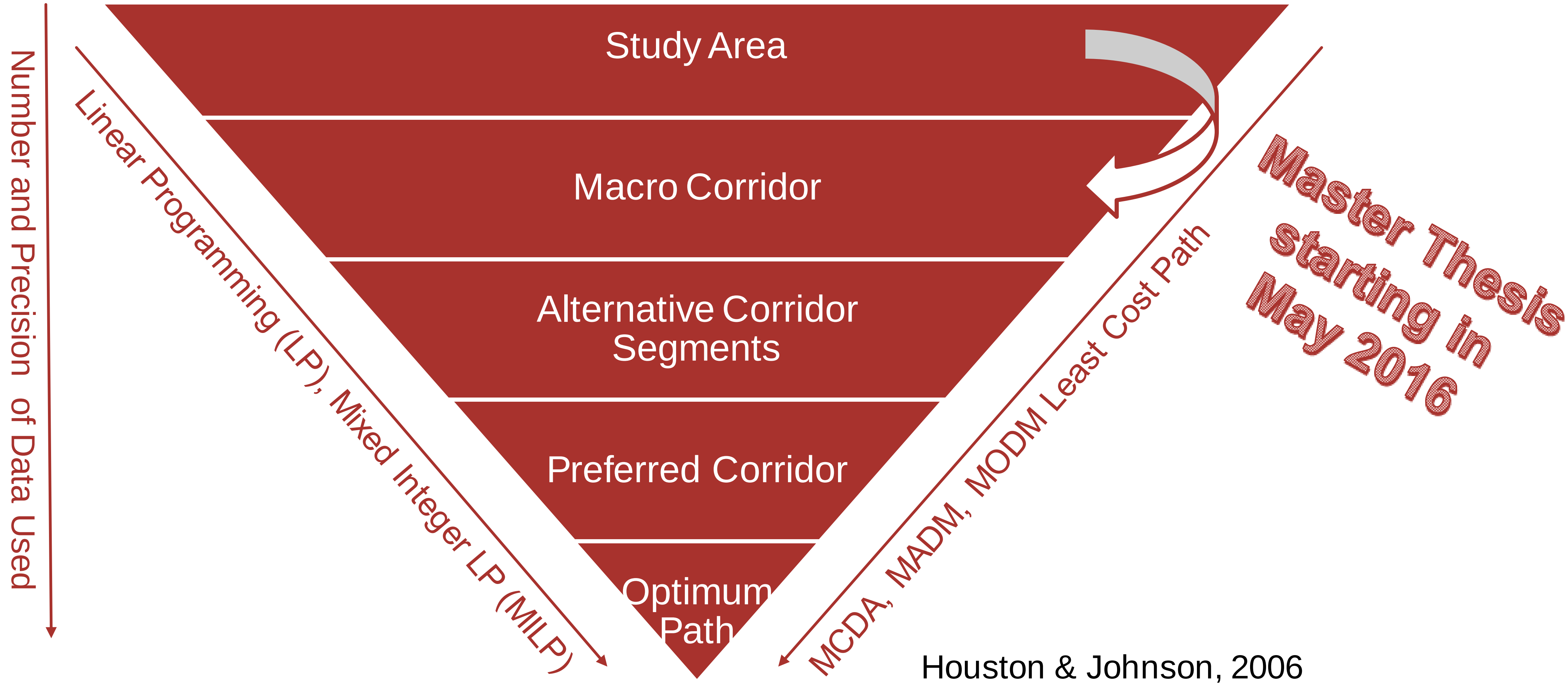
May–November 2016: Funnel Approach Is also Required in Switzerland

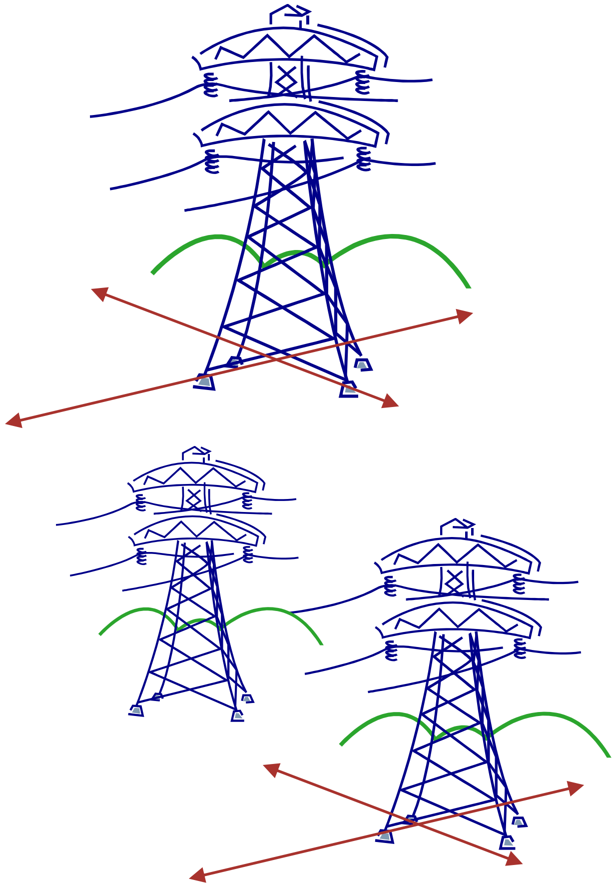


Houston & Johnson, 2006

May–November 2016: Still, the Pylon Positioning Problem Has not Been Solved

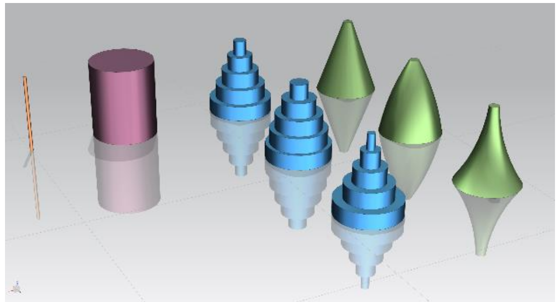
- No hands-on algorithm exists yet which suggest a reliable pylon positioning.
- Problem: LCP is raster-based whereas algorithms used for positioning optimization typically are vector-based.

Master Thesis starting in May 2016



April – September 2016: Validate and Improve the Algorithm

- Conduct statistical studies about the model's robustness by the use of sensitivity analyses.
- Output CSVs containing information about the underlying rasters.
- Validate other approaches that vary the cost surface and thus, optimize the LCP/LCC.
- Implement a cost calculation approach.
- Evaluate a questionnaire sent to experts to determine threshold values and buffer slopes.
- Conduct studies about different buffering approaches, especially for zonal statistics.



Imagine an Application in which a Power Grid Could Be Planned in 3D and Allows

Interaction

Communication

Data Upload: SHP, CSV, Pylons

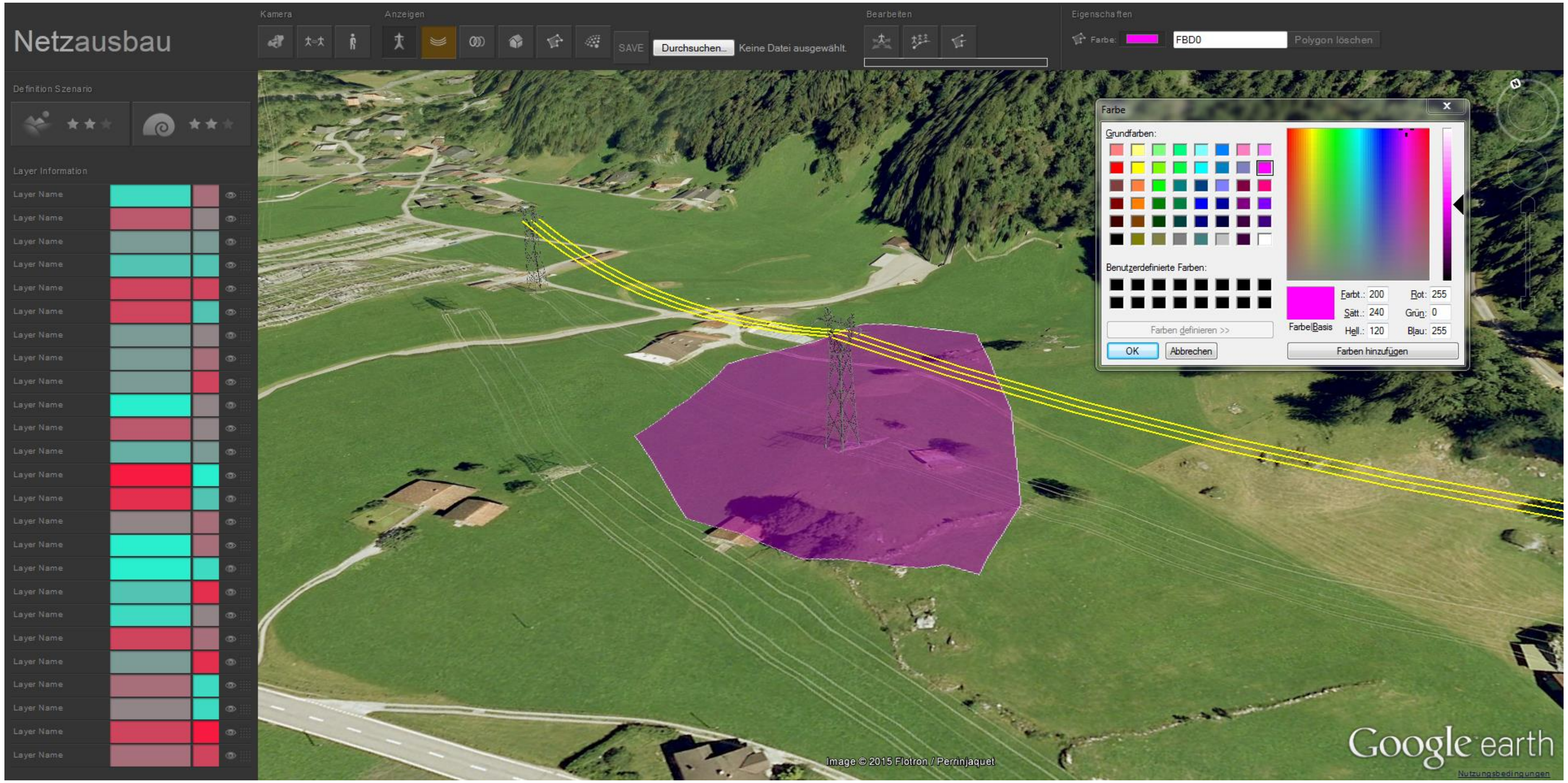
Realistic Impressions

LiDAR Data Integration

Exchange of Ideas

Weighting

Cost Estimation



Discussion

Open Questions? Don't hesitate to ask.

Thank you for your attention