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**Desktop and Web GIS based Spatial Decision
Support System for site selection of wind farms**

- Applied in the State of Baden-Württemberg (Germany) -

by

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A dissertation presented in partial fulfillment of the requirements for the degree of Master of Science in the Department of Geomatics, Computer Science and Mathematics, Stuttgart University of Applied Sciences

Declaration

The following Master thesis was prepared in my own words without any additional help. All used sources of literature are listed at the end of the thesis.

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Stuttgart, 29.03.2012

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Prof. Dr.-Ing. Franz-Josef Behr

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Master Course Photogrammetry and Geoinformatics

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Abstract

Wind energy production is one of the fastest growing sectors of modern economy, leading to the installation of a great number of new turbines all over the world. Planning the exploitation of wind resources entails a complex decision making process including diverse criteria which importance depends not only on the decision makers' interests but also on the geographical area where the wind farm is planned to be installed. The purpose of this thesis was the development of two Spatial Decision Support Systems based on Geographical Information Systems in order to assist the decision makers in the preliminary site selection of wind farms.

One was developed as a desktop application adaptable to any kind of wind energy project, extending the functionalities of the software ModelBuilder for ArcGIS Desktop with Python programming language. The other was designed according to the needs of the "Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg" (Germany) and it will be implemented as a Web application for ArcGIS Server.

Both are able to automatically perform the spatial analysis required to find the most suitable locations for wind farms, according to the users' criteria and as a Transparent To The User technology, not demanding any knowledge in the involved technologies.

Keywords: Wind energy, automation, Python, ModelBuilder, ArcGIS.

Table of Contents

Acknowledgement.....	i
Abstract	ii
Table of Figures	vi
Table of Tables.....	ix
Abbreviations.....	x
1 INTRODUCTION	1
2. LOCATION & PURPOSE	3
3. THEORETICAL & TECHNICAL BACKGROUND.....	4
3.1 Wind Energy	4
3.1.1 Importance and trends	4
3.1.2 Advantages and disadvantages	4
3.2 Wind farms	5
3.2.1 Wind turbine power curve.....	5
3.2.2 Technical requirements of wind farms	6
3.2.3 Environmental impacts	8
3.2.4 Criteria of restriction and exclusion	13
3.2.5 Protected areas in Baden-Württemberg	13
3.3 Spatial Decision Support Systems.....	14
3.3.1 Spatial Decision Support Systems for wind farms	14
3.4 Overview to the ArcGIS 10 system	15
3.5 Automation of geoprocessing with ArcGIS Desktop	16
3.5.1 Modeling in ModelBuilder	17
3.5.2 The functionality of Python	18
3.5.3 Graphical User Interface with Tkinter and Tix	19
3.5.4 Importance of the OS and Arcpy libraries	19
3.6 Raster and vector formats	20
3.7 Fuzzy logic.....	20
3.8 ArcGIS Server	21
3.8.1 The ArcGIS Server system architecture	21

3.8.2 Publication of geoprocessing services	22
3.8.3 Web application.....	22
4. LITERATURE REVIEW.....	23
4.1 GIS for site selection of wind farms.....	23
4.2 SDSS for site selection of wind farms	23
4.3 Web based GIS for site selection of wind farms.....	24
5. AIMS & OBJECTIVES.....	24
6. RESEARCH QUESTIONS & HYPOTHESIS.....	25
7. DATA, HARDWARE & SOFTWARE	26
7.1 Data	26
7.2 Hardware	26
7.3 Software	27
8. METHODOLOGY.....	28
8.1 General overview.....	28
8.2 Phase A: Design and development of the SDSSs.....	29
8.2 Phase B: Development of the desktop application	30
8.3 Phase C: Development of the Web application.....	31
9. OUTCOMES.....	32
9.1 ModelBuilder	32
9.1.1 Purpose of the designed models	32
9.1.2 Description of the models' design.	33
9.1.4 Comparison of the models: Test applied in the State of BW	37
9.2 Desktop application.....	60
9.2.1 Purpose: Advantages over ModelBuilder	60
9.2.2 Software Requirements Specification (SRS)	63
9.2.3 Interface explanation.....	66
9.3 Web application.....	82
9.3.1 Preparation of the geoprocessing tasks	82
9.3.2 Publication and development of the Web application.....	83
9.3.2 Difficulties	84
10. CONCLUSIONS & DISCUSSION	86

11. RECOMMENDATIONS	89
ANNEX I: Spatial analysis performed in ModelBuilder	90
ANNEX II: Menus and pop up messages.....	134
REFERENCES.....	137

Table of Figures

Figure 1: Idealized power curve	6
Figure 2: Symbols in ModelBuilder	17
Figure 3: Symbols used inside the models	35
Figure 4: Complete model 1	36
Figure 5: Entire model 2 and 3	37
Figure 6: Technical specifications E-70 E4	40
Figure 7: Selected wind resources for model 1	41
Figure 8: Selected wind resources for model 2	42
Figure 9: Selected wind resources for model 3	43
Figure 10: Results from Wind resources models	44
Figure 11: Results from Slopes models	45
Figure 12: Selections and exclusions of Roads models 2 and 3	48
Figure 13: Results from Roads models	49
Figure 14: Relation Wind resources and Roads	50
Figure 15: Results from Railways models	51
Figure 16: Relation Wind resources and Railways	51
Figure 17: Results from Land Use models	52
Figure 18: Relation Wind resources and Settlements	53
Figure 19: Results from Water models	54
Figure 20: Relation Wind resources and Water bodies.	55
Figure 21: Results from Natural Protected Areas models	56
Figure 22: Relation Wind resources and Natural Protected Areas	57
Figure 23: Final outputs of Models	58
Figure 24: Final outputs of model 2 and 3	59
Figure 25: Dialog box for a Land Use in ModelBuilder	62
Figure 26: Land Use in the desktop application	62
Figure 27: Installation instructions	64
Figure 28: SDSS folder	65
Figure 29: Welcome tab	66
Figure 30: Data preparation tab: Instructions	67
Figure 31: Data preparation tab: Required data	67
Figure 32: Data preparation tab: Required data	68
Figure 33: Data preparation tab: Raster-Vector transformations	69
Figure 34: Data preparation tab: Limit your area of study.	70
Figure 35: Data preparation tab: Resampling your rasters.	71
Figure 36: Data preparation tab: Refresh "Input_Data.gdb"	71
Figure 37: Technical requirements tab.	72
Figure 38: Technical requirements tab: Wind resources	73
Figure 39: Technical requirements tab: Terrain slope	73
Figure 40: Technical requirements tab: Roads	74
Figure 41: Technical requirements tab: Power lines	74
Figure 42: Abiotic impacts tab	75

Figure 43 Abiotic impacts tab: Railways.....	75
Figure 44: Abiotic impacts tab: Land Use.....	76
Figure 45: Abiotic impacts tab: Water.	76
Figure 46: Abiotic impacts tab: Restricted or protected areas	77
Figure 47: Biotic impacts tab.....	77
Figure 48: Biotic impacts tab: Natural Protected Areas.....	78
Figure 49: Site Selection tab.....	79
Figure 50: Export of the final output.....	81
Figure 51: Wind resources submodel for the Web application	83
Figure 52: Web application developed with Server Manager.....	84
Figure 53: Symbols used inside the models	90
Figure 54: Wind Resources in model 1.....	91
Figure 55: Wind Resources in model 2.....	92
Figure 56: First selection of Wind Resources in model 2	93
Figure 57: Calculation of final Wind Resources in model 2.....	94
Figure 58: Wind Resources in model 3	95
Figure 59: Intermediate outputs of Wind Resources in model 3.....	96
Figure 60: First selection of Wind Resources in model 3	97
Figure 61: Calculation of final Wind Resources in model 3.....	98
Figure 62: Slopes in model 2	99
Figure 63: Intermediate outputs of Slopes in model 2.	101
Figure 64: Slopes in model 3..	102
Figure 65: Roads in model 1.....	104
Figure 66: Roads in model 2.....	105
Figure 67: First selection of Roads in model 2.	107
Figure 68: Total selected roads calculation of model 2.	108
Figure 69: Roads in model 3.....	109
Figure 70: Intermediate outputs of Roads in model 3.	110
Figure 71: First selection of Roads in model 3.	111
Figure 72: Calculation of final Roads in model 3.....	112
Figure 73: Power lines in model 2.	113
Figure 74: Power lines in model 3	115
Figure 75: Railways in model 2.....	116
Figure 76: Railways in model 3.....	118
Figure 77: Land Use in model 1.....	119
Figure 78: Land Use in model 2.....	119
Figure 79: First selection of Land Use in model 2	120
Figure 80: Calculation of final Land Use in model 2.....	121
Figure 81: Land Use in model 3.....	122
Figure 82: First selection of Land Use in model 3.	123
Figure 83: Fourth selection of Land Use in model 3.....	124
Figure 84: Water in model 1.	125
Figure 85: Water in model 2	126
Figure 86: Water in model 3.	127

Figure 87: Ausschlussflächen model.....	128
Figure 88 Pruffungsflächen model	129
Figure 89: Geoprocessing of FND in Ausschlussflächen model.....	130
Figure 90: Geoprocessing of SPAs in the list.	130
Figure 91: Geoprocessing of SPAs not in the list.....	131
Figure 92: Complete model 1.	132
Figure 93: Entire model 2 and 3	133
Figure 94: User friendly: Pop up messages.	134
Figure 95: Menus.	134
Figure 96: Wind energy and the SDSS menu: About SDSS.	134
Figure 97: Wind energy and the SDSS menu: Index of the SDSS.....	135
Figure 98: Help menu: Welcome tab.	135
Figure 99: Help menu: Data preparation.	136

Table of Tables

Table 1: Main environmental components affected by wind farms	9
Table 2: Maximum levels of noise allowed in Germany.....	10
Table 3: Hardware requirements	26
Table 4: Created model parameters.....	34
Table 5: Criteria and weights.....	38
Table 6: Speeds of geoprocessing for selected criteria	39
Table 7: Criteria established in the Regional Plan of the Donau	46
Table 8: Optional inputs with Pyhon I	61
Table 9: SISEWIFA 1.0 system requirements.....	64
Table 10: Optional inputs with Pyhon II	78

Abbreviations

ADF	Application Developer Framework
API	Application Programming Interface
BW	Baden-Württemberg
COM	Component Object Model
DSS	Decision Support System
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
GIS	Geographical Information Systems
GUI	Graphical User Interface
IDLE	Integrated Development Environment
IIS	Internet Information Services
LUBW	Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg
SDSS	Spatial Decision Support System
SOC	Server Object Container
SOM	Server Object Manager
TTTU	Transparent To The User
UM	Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg

1 INTRODUCTION

The interest in renewable energy has increased since the energy crisis of 1973 (Michalak & Zimny, 2011). Reasons like shortage of fossil fuels, external energy dependence and the environmental consequences derived from non-renewable energies have boosted governmental policies to promote the use of renewable resources (Ramirez-Rosado *et al.*, 2008). Wind energy stands out among them, being one of the fastest growing sectors of modern economy (Michalak & Zimny, 2011) and providing a free and inexhaustible resource distributed all over the world, which is able to compete with traditional hydrocarbons.

Planning the installation of wind turbines carries a complex decision making process in which a multi-criteria spatial analysis is essential to ensure the profitability of a wind farm. For example, an installation of turbines far away from roads prevents from visual impact but increases the construction and maintenance costs. Besides, the importance of these criteria (technological, socio-economic, political and environmental) depends on the geographical area where turbines are planned to be installed. For instance, the noise generated by turbines usually causes less nuisances in industrial than in urban areas. Furthermore, the installation always involves decision makers with diverse interests which tend to generate different alternatives for the same project, prolonging the decision making process. Some examples are investors more focused on economical aspects, government on short-term results and ecologist on environmental consequences.

On the one hand, numerous multi-criteria spatial problems require decision making (Keller & Strapp, 1996) where Decision Support Systems aid in rapidly finding effective solutions (Ramirez-Rosado *et al.*, 2008) due to their analytical capacity and search procedures (Keller & Strapp, 1996). On the other hand, manipulation and visualization of data is also required to generate alternatives and analyze “what if” scenarios. Geographical Information Systems (GIS) offer the perfect technology.

The aim of this thesis is the development of a GIS based Spatial Decision Support System (SDSS) capable of automatically find most suitable locations for wind turbines according to the decision makers’ priorities. Furthermore, it will be designed as a TTTU technology (Transparent To The User), not requiring knowledge in the involved technologies. This way, the specialists in environmental sciences and wind energy shall need only to analyze and choose between the generated alternatives of location.

The application ModeBuilder from the software ArcGIS will be used to achieve automation. A disadvantage derived from this software is the mandatory analysis of all the included criteria. In order to overcome this obstacle and increase flexibility in the decision making process, a desktop application will be programmed in Python language so that all the parameters become optional.

Moreover, the advantages offered by Web technologies to spread services and data over the Internet have motivated the development of a Web application, which will deposit the costs of the software license on the server side and dismiss the temporal and local barriers for potential clients of the SDSS.

Structure of the thesis

Part of this thesis is focused on the development of a SDSS for the State of Baden-Württemberg (BW); a detailed description of what will be done, for whom, how and where is given in the next section. Theoretical and technical descriptions related to the thesis' background as well as a reference to researches that are relevant to the field of study can be found in chapter 3 and 4. A description of the pursued objectives, uncertainties and expectations evolved during the thesis are given in chapters 5 and 6. The data, hardware and software used for the development and test of the SDSS are described in chapter 7.

Three main phases will be applied to achieve the proposed objectives; design of the SDSS in ModelBuilder for ArcGIS 10 Desktop, development of a desktop application with Python 2.6 and development of a Web application with ArcGIS Server 10. An overview of the planned methodology is described in chapter 8. Besides, the chapter 9 includes a specific and more detailed methodology, an analysis of the resulting outcomes and the conclusions derived from each phase. The final conclusions and discussions are included in chapter 10.

Additionally, a serial of video documentation regarding the desktop application are included in the CD, which will be referenced during the thesis' document.

2. LOCATION & PURPOSE

What, why, for who and how?

Two GIS based Spatial Decision Support Systems for wind farm sitting will be developed in order to be accessed as desktop and Web applications.

The main purpose of the desktop application is the extension of ModelBuilder's functionality by making all the inputs optional and designing a self-explanatory user friendly interface. Users shall be capable of automatically distribute suitability weights between the most common patterns analyzed by Environmental Impact Assessments (EIAs), without knowledge of the involved technologies, with the aim of assists wind energy projects in the first site selection of wind turbines as well as in the evaluation of project's alternatives. This application will be accessed though a Graphical User Interface (GUI) developed in Python language and the GUI programming toolkit Tkinter.

The Web based SDSS will be designed for the "Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg" (LUBW), a public institution in charge of environmental, nature and radiation protection, health, occupational and product safety in the State of Baden-Württemberg (<http://www.lubw.baden-wuerttemberg.de>). It is under the supervision of the "Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg" (UM), the Ministry in charge of environment, climate and energy economics issues, which will be the final user of the developed SDSS. It will be designed as a political tool of assessment in the installation of wind turbines in the State of Baden Württemberg, with the aim of identifying suitable wind resources within the State and reject those located on restricted and protected areas as well as their surroundings, where environmental constrains are the predominant criteria. The application will be accessed through an intranet developed with ArcGIS Server 10.

Where and why?

This project focuses on Germany, where wind energy is the major renewable resource, being implemented in the State of Baden-Württemberg, one of the States with less installed wind capacity (Weigt, 2009) and whose Government plans to supply a 10% of the total electricity demand with wind power by 2020. Therefore, this ambitious plan requires the installation of a great number of new turbines owing to the fact that wind supply reached only a 0.8% share in 2009 (Betken, 2011).

Furthermore, Germany plans to switch off all its nuclear plants by 2022 (BBC, 2011; Breidhardt, 2011), leading to a shortage of energy that needs to be replaced.

3. THEORETICAL & TECHNICAL BACKGROUND

3.1 Wind Energy

3.1.1 Importance and trends

Wind energy production is one of the fastest growing sectors of modern economy (Michalak & Zimny, 2011) where many countries have experienced a great and sudden growth during the last years (Schmidt, 2007). As a matter of fact, while the global cumulative wind power capacity approached only 48 GW in 2004, representing 0.57% of the total world electricity supply (Munteanu *et al.*, 2008), it already reached 94 GW in 2007 and maintains an average growth rate of 25% (European Wind Energy Association, 2009).

Europe is leader in wind energy technology, having installed in 2007 the 60% of the world's wind power capacity (European Wind Energy Association, 2009). Actually, 10,281 MW of wind power were installed in Europe only during 2011, where Germany is by far the largest market, followed by UK, Spain, Italy, France and Sweden (European Wind Energy Association, 2012).

3.1.2 Advantages and disadvantages

Advantages:

Wind resources are available all over the world, offering a free (null costs of the resource) and renewable energy (Schmidt, 2007).

According to Gevorkian (2006, p.254), "the technology is mature and energy production is relatively inexpensive", actually "Wind turbines are one of the best means to provide electric energy in third-world countries". Furthermore, payback of initial investments is the smallest among modern energy conversion technologies, being estimated from one to twelve months at maximum (Armaroli & Vincenzo, 2010).

Since wind energy reduces the need of electricity generated by other sources, it also reduces the adverse environmental impacts related to them. For example, there are no impacts for extracting the resource, no emission of atmospheric pollutants, no need to build dams or water for cooling (Armaroli & Vincenzo, 2010), no nuclear residuals and degradation of landscapes (CEIWEPE & NRC, 2007).

Additionally, turbines' footprints occupy a small surface and almost 99% of the area can still be used as before (Wizelius, 2007) if wind parks are compatible with existing land uses.

Disadvantages:

On the one hand, the variable nature of wind resources, the difficulties of dispatching this power and storing electric energy have forced wind power fluctuations to be balanced with other types of generation (Schmidt, 2007).

On the other hand, there are some environmental impacts related to wind energy such as noise, visual impact, disruptions in water or habitats (CEIWEP & NRC, 2007) and although this energy is produced without generating atmospheric pollution (Gevorkian, 2006); there is still a disruption in the air (CEIWEP & NRC, 2007).

3.2 Wind farms

Wind energy is generated by turbines, devices which transform the kinetic energy present on the wind into mechanical energy capable of producing electricity. Consequently, the quantity of energy that a turbine is able to extract from the wind will depend on the speed and is essential to determine the final energy production. This relationship is represented by the power curve (explained in the next section). Another crucial element for the profitability of a turbine is the tip speed ratio, ratio between the rotational speed of the tip of a turbine's blade and the undisturbed wind speed (Earnest & Wizelius, 2011). Turbines can be installed alone or gather in the same location conforming wind farms.

3.2.1 Wind turbine power curve

According to Masters (2004, p.355) "The most important technical information for a specific wind turbine is the power curve, which shows the relationship between wind speed and generator electrical output". There are three important thresholds in this curve (see figure 1):

1. **Cut-in speed:** Wind speed at which turbines start to deliver useful power (Manwell *et.al*, 2009). Lower speeds are not useful because they are not able to overcome friction in the drive train of a turbine or because the generated power is not enough to offset the one required by the generator field windings (Masters, 2004), which converts mechanical energy into electrical.
2. **Rated wind speed:** Speed at which the maximum power output of an electrical generator is produced (Manwell *et.al*, 2009). Once the cut-in threshold has been reached, energy production tends to increase as the cube of the speed until the rated wind speed; afterwards generator delivers as much power as it has been designed for (Masters, 2004).
3. **Cut-out speed:** Maximum wind speed at which turbines are allowed to produce electricity due to safety constrains (Manwell *et.al*, 2009). After this speed is reached, turbines must be shut down in order to avoid mechanical damages, ergo there is no output power above this wind speed.

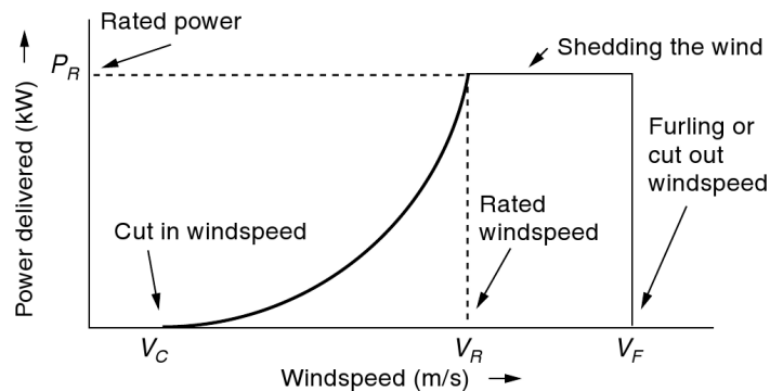


Figure 1: Idealized power curve (Masters, 2004, p. 335). Turbines start to produce energy after their cut-in speeds (V_C), increasing power as the cube of wind speed. When rated speed is reached (V_R), turbines generate their maximum production. Afterwards, turbines are shut down after their cut-out speeds (V_F), in order to avoid mechanical damages.

3.2.2 Technical requirements of wind farms

To predict how efficient a wind farm can be is a complex process where many factors are involved. Apart from the potential energy production, other constraints must be taken into consideration in order to guarantee its profitability. The main technical requirements to consider in the exploitation of wind energy are:

1. **Wind resources:** Is one of the most important factors to ensure the viability of a project (Tong, 2010), indeed the prediction of long-term wind regimen is essential for wind farm siting (European Wind Energy Association, 2009).

Wind regimen can be modeled based on meteorological and orographic data, and represented by wind resources maps according to the annual average speeds or powers available in a certain area (McElroy, 2009). Actually, many of these maps have been already produced for large areas and a wide range of scales, representing wind resources at specific heights (Tong, 2010).

Wind determines energy production. On the one hand, wind turbines usually start generating electricity after a minimum speed of 11-22 Km/hour, depending on the type and size of the turbine. On the other hand, higher speeds generate turbulences that might damage the turbines because of mechanical or generator stress. Consequently, turbines are normally switched-off when wind speeds exceed the 70-110 Km/hour (Jogi, 2000).

Apart from wind resources, the European Wind Energy Association (2009) determines other criteria required to calculate energy production, such as farms layout, hub height, turbines characteristics, turbulences or topography. Therefore, once wind resources are adequate, location and design will be the critical factors in determining the final energy production.

2. **Size of final location:** Cost of installation and operation must be counteracted with the profits of energy production, which depends not only on the design but also on the wind farm dimensions.

The area of a turbine's foundations varies from 200 to 400 m² (Hau, 2005). For example, according to Wizelius (2007, p.154), "A group of twelve 1.5 MW turbines in a 3x4 group require an area of 81 ha." "However, 99% of this area can still be used as before, so the actual land requirements is only 4.5 ha/Mw", provided that the land uses are compatible.

3. **Turbulences:** Presence of wind turbulences is related to orography (height variation of terrain), obstacles and wind farm layout, being able to affect the energy production.

Orography has an influence on wind direction. According to Tong (2010, p.80) "While in flat terrain the wind speed increases with height, steep slopes might lead to a decrease with height", especially when the flow does not follow the shape of the terrain. Turbulences are likely to happen in terrains steeper than 30% or 17° slope (Tong, 2010) and they might abruptly change the wind direction forcing the flow to hit turbines' blades with an unprofitable angle.

Obstacles might also lead to negative impacts in energy production. As mentioned by Tong (2010, p.80) "If wind turbines are located closely behind obstacles like for example a forest the vertical wind speed profile might be again heavily distorted", leading to an inadequate flow direction towards the turbines.

Layout is also a factor to take into consideration. Turbines extract the kinetic energy from the wind which flows towards them. This extraction generates a conical area behind the turbines where turbulences are present and wind speed is reduced. Ergo a minimum distance between each pair of turbines is advisable, as well as between these and other existing obstacles like forest or cliffs (Tong, 2010).

4. **Road network:** Roads are needed for delivery, assembly and maintenance of turbines. According to Wizelius (2007, p.242), "The costs of access roads depends on the size and weight of the turbine, ground conditions and the length of road that has to be built."

Not all roads are adequate for the transportation of turbines' parts. Indeed, the network's characteristics are going to determine the width and size which roads are able to handle. For example, road transportation might not be adequate enough in the case of 100 kW turbines, requiring expensive helicopter transport (Hunter & Elliot, 1994).

Therefore a logistics analysis should be performed in order to secure that the existing transportation network is adequate or plan if other alternatives should be considered in the project's budget.

5. **Power lines:** The capacity of a grid determines the quantity of energy that can be connected to a power line. In consequence, technical requirements like the voltage level, power flows or dimensions of the lines must be taken into consideration during the wind farm design (Wizelius, 2007).

According to Tong (2010, p.29), "Wind is a highly intermittent energy source for causing overall fluctuation in wind power generation", making the suitability of a power line to depend on the peaks of energy production. As reference, 3.5 MW can be connected to a 10 kV line and 60 MW to a 40 kV line (Wizelius, 2007).

Once the adequate lines have been identified, turbines should be installed within a minimum distance from them so that the costs of connecting wind generators to the electrical network are economically viable. In fact, developers are responsible of these costs and since price per kilometer of cable is significant (Wizelius, 2007); distance plays an important role in the site selection process.

3.2.3 Environmental impacts

Wind energy has a global positive impact on the Environment, considering the renewable energy production and the displacement of counterproductive effects generated by other energy sources (CEIWEF & NRC, 2007). Indeed, according to Armaroli & Vincenzo (2010, p.241) "Wind power has definitely one of the lowest environmental footprints among all the electricity generation technologies". But still some environmental impacts are generated which affect the Environment on its abiotic (non-living) and biotic (living) components, where the biggest affections are visual impact, noise and birds' collision (Armaroli & Vincenzo, 2010).

Since projects can be delayed or denied because of environmental restrictions, their analysis is convenient and in occasions mandatory to acquire permissions of construction.

The main components of the environment affected by wind farms are listed in the table 1 and described in the following pages.

Table 1: Main environmental components affected by wind farms.

Environment	Component	Element
Physical	Atmosphere	Noise Air quality Climate
	Hydrosphere	Superficial waters
Biotic	Biosphere	Birds and bats Protected habitats
		Public health Landscape: Visual Impact Land use Land ownership
Socioeconomic	Cultural heritage	Historical Sacred Archeological
		Electromagnetic Interference Economical impacts

Physical environment

1. **Noise:** There are two sources of noise. The first one is an aerodynamic noise generated by the movement of blades, not audible over long distances and being masked by the wind if a minimum distance (buffer) from dwellings is established (Ottinger & Bradbook, 2007). The second one is a mechanical noise associated to gearboxes and generators, which modern turbines have minimized through insulation materials (European Wind Energy Association, 2009). In consequence, the resulting level of noise depends on several factors, such as type and size of turbines, layout of wind farms, speed and direction of winds, topography and ambient noise (European Wind Energy Association, 2009).

Although it has not been proved so far that the generated noise has direct impacts on health (Pedersen & Halmstad, 2003), it should be taken into consideration. Indeed, diverse legislations have established minimum noise levels depending on the existing land uses. In the case of Germany, these levels are specified in the TA Lärm (Technische Anleitung zum Schutz gegen Lärm, 1998), showed in Table 2.

Actually, considering that a modern turbine of three-bladed rotors with a tip-speed ration of 6 generates around 95 dB(A) for small turbines up to 20 m rotor diameter and of 100 kW (Hau, 2005), a certain distance is usually required.

Table 2: Maximum levels of noise allowed in Germany. This table includes the technical indications of protection against noise depending on land use and according to German legislation. The table has been created from the Technische Anleitung zum Schutz gegen Lärm (TA Lärm 1998) article 6.1 "Immissionsrichtwerte für Immissionsorte außerhalb von Gebäuden" (emission values for immissions outside buildings).

Land Use	dB(A)	
	at day	at night
Industrial area (Industriegebieten)	70	
Comercial estate (Gewerbegebieten)	65	50
Mixed industrial and residential (Kerngebieten, Dorfgebieten und Mischgebieten)	60	45
Predominantly residential and small settlements (in allgemeinen Wohngebieten und Kleinsiedlungsgebieten)	55	40
Purely residential area (in reinen Wohngebieten)	50	35
Areas with SPA, hospitals and nursing areas (in Kurgebieten, für Krankenhäuser und Pflegeanstalten)	45	35

2. **Air quality and climate:** Although there is no emission of pollutants, extensive use of wind energy is interrelated to climate change. On the one hand, climate change is able to modify wind patterns, changing the distribution of useful kinetic energy and consequently the productivity of a wind farm (Armaroli & Vincenzo, 2010). On the other hand, extensive exploitations might also have effects on climate, according to Armaroli & Vincenzo (2010, p.241) "wind power might produce non-negligible climate change at continental scales, but with unimportant effects on global mean surface temperatures."
3. **Hydrology:** Wind energy is one of the most benign sources of energy regarding the stress on water resources, especially considering that wind installations do not need water cooling systems like the nuclear, geothermal, fossil and solar central receiver systems (Abbasi & Abbasi, 2004). But some effects might be derived from large scale exploitations due to a slowdown in wind speeds. The consequence is a reduction in the rate of evaporation from lakes' surfaces, what warms the water (Abbasi & Abbasi, 2004) and might stress the aquatic ecosystems.

Biotic environment

1. **Birds and Bats:** According to Manwell *et al.* (2009, p.550) wind energy can generate "bird electrocution and collision mortality; changes to birds foraging habits; alteration of migration habits; reduction of available habitat; disturbance to breeding, nesting and foraging". Actually, the rotation speeds of the blades for large turbines at normal operation can be higher than 70m/s and thus birds and bats can be easily hurt (Tong, 2010). The minimum distance needed to prevent this of happening will depend not only on the turbines' characteristics but also on the flight patterns of the considered species.

2. **Habitats:** Wind energy also affects ecosystems and might reduce the habitat of some species. For example, the construction and maintenance phases imply vegetation clearing, soil disruption, potential erosion and creation of openings which might alter microclimates and the ecosystems' structure (CEIWEP & NRC, 2007).
3. **Protected nature areas:** Diverse legislation protects nature areas at international, national and regional level. Some of the main protected areas designed under international conventions and European Directives are:
 - **Biogenetic Reserves:** Protection of representative European wildlife and natural areas by the Council of Europe (Morris & Therivel, 2009).
 - **Biosphere Reserves:** Promotion of sustainable use in terrestrial and coastal ecosystems by the "Man and the Biosphere" program of the UNESCO (Morris & Therivel, 2009).
 - **Ramsar Sites:** International protection of wetlands by the Ramsar Convention (Morris & Therivel, 2009).
 - **Special Protection Area (SPA):** International protected area within the EU established by the Directive 79/409/EEC for Conservation of Wild Birds (Langston & Pullan, 2004).
 - **Special Area of Conservation (SAC):** International protected area within the EU established by the Directive 92/43/EEC for Conservation of Natural Habitats and of Wild Flora and Fauna (Langston & Pullan, 2004).
 - **World Heritage Sites (WHS):** Protected areas for their cultural and natural interest designed by the World Heritage Convention (Morris & Therivel, 2009).
 - Other figures of protection are local or national Natural Reserves and National Parks.

Socioeconomic environment

1. **Public health:** Wind farms have positive and negative impacts on public health. Positives are derived from the substitution of conventional source of energy production and negatives are caused mainly by noise and shadow flicker (CEIWEP & NRC, 2007).

Shadow flicker implies changes in light intensity due to the movement of turbines' blades which rotates moving their shadows. It might generate nuisances for the population and distraction of drivers in the case that turbines are installed too close to roads (CEIWEP & NRC, 2007). Even though, nowadays there are many examples of large turbines installed very close to buildings or main roads like in Westerwald, Germany (Harries *et al.*, 2009).

Other related safety risks are blade throw, falling ice or tower failure (Manwell *et al.*, 2009), but these accidents have been generally related to extreme wind conditions or poorly designed installations (Harries *et al.*, 2009).

- Landscape, Visual Impact:** According to Manwell (2009, p.556) “Aesthetic issues are often a primary reason for concern about wind projects”. Considering that wind turbines are vertical structures which need to be installed in exposed and elevated areas in order to exploit wind resources, visual impacts are frequent. According to Hau (2005) “Turbines with less than 50m height are usually masked easily in most cultivated and built-up landscapes. Wind turbines with a height exceeding 50m dominate the landscape over long distances.” Nowadays, modern large turbines are higher than 100m (Tong, 2010).

This impact is difficult to measure since the public’s perception is subjective and depends on factors like the population’s knowledge on wind energy, location of turbines (Manwell *et al.*, 2009) and landscape’s sensitivity, which is defined by Karen (pg.31, 1999) as the “ability of the landscape to withstand development without losing quality”. In any case, it always decreases with distance (European Wind Energy Association, 2009).

- Land use:** Turbines’ footprints use only from 1 to 10% of the wind farm area and there are many examples where turbines have been installed without substantially disturbing existing land uses such as cultivation, grazing or recreation (Armaroli & Vincenzo, 2010) because they are compatible with wind farming. For the rest of land uses and depending on the characteristics of a project, a minimum distance must be kept to avoid visual impact, noise or for security reasons.

Furthermore, according to Manwell *et al.* (2009, p.584) “on some wind farm projects, the resource managers for adjacent properties have established lease or permit conditions such that wind farm development on one site does not block the use of wind resource on adjacent sites”.

- Land ownership:** Owners need to agree during the construction, operation and maintenance phases.
- Cultural heritage:** According to CEIWEP & NRC (2007, p.156) “Historic, sacred, and archeological sites and settings must be regarded as sensitive sites.” Possible negative impacts might be the degradation of elements during the construction and maintenance phases or an aesthetic impact in the landscape.
- Electromagnetic interference effects:** Since wind turbines can reflect, scatter or diffract electromagnetic waves, they are likely to affect the telecommunication signals like radio, TV, cellular telephones or radar (Manwell *et al.*, 2009).
- Economical impacts:** Governmental policies usually offer monetary incentives to encourage wind energy production. Besides it is a source of employ with variety of skills and payrolls (CEIWEP & NRC, 2007).

3.2.4 Criteria of restriction and exclusion

Visual impacts, noise, electromagnetic interference effects, shadow effects, safety risks or other negative impacts recommend or does not allow installing wind turbines within a minimum distance (buffer) from:

- Dwellings.
- Water bodies such as streams, lakes or coasts.
- Transportation and telecommunication networks.
- Restricted areas such as airports or military areas.
- Protected areas because of archeological, historical, cultural or natural protection.

3.2.5 Protected areas in Baden-Württemberg

The State of Baden-Württemberg contains the following protected areas according to LUBW (<http://www.lubw.baden-wuerttemberg.de>):

- **Naturschutzgebiet** (NSG, Natural reserve): Areas established for the protection of species and ecotypes (Atkinson *et al.* 1990). It implies special protection for nature and landscapes because of natural history or regional reasons and for the conservation of habitats or biotopes of wild animals and plants (LUBW).
- **Landschaftsschutzgebiet** (LSG, Landscape Protected Area): Defined by Atkinson *et al.* (1990, p.24) as “areas established primarily for the protection of rural and scenic landscapes including geological features.”
- **Natureparke** (Nature parks): Large areas for landscape protection and nature conservation (LUBW).
- **Flächennaturdenkmäler** (FND, Natural monuments): According to Atkinson *et al.* (1990, p.25) they are “natural elements, such as geological features, ancient trees or natural objects often associated with historical events.”
- **Biosphärengebiete** (Biosphere areas): They include cultural landscapes with distinctive and rich natural environment (LUBW).
- **Gesetzlich geschützte biotope** (legally protected habitats): For the protection of valuable and vulnerable habitats (LUBW).
- **Waldschutzgebiete** (Forest reserves): Forest protected areas.
- **Bannwälder** (Protective forest against avalanches).
- **Schonwälder** (Forest reserve): Protection of rare forest communities or habitats (LUBW).
- **Natura 2000 Gebiete** (Natura 2000 areas): Protection of areas from the net Natura 2000.

3.3 Spatial Decision Support Systems

Degroote & Sugumaran (2010) define a Spatial Decision Support System (SDSS) as an interactive computer based system to aid the decision makers in solving complex spatial problems with the maximum effectiveness. Actually, a SDSS could be considered as a combination of a Decision Support System (DSS) and a GIS. While the DSS provides the analytical modelling capability of a decision making process, the GIS integrates the spatial component (Simão *et al.*, 2009) and the capability to create, manage, query and display geographical data.

They can be accessed as desktop and Web applications. In the last case, a server is required to host and provide the SDSS service to the clients; relationship that is commonly built with user interfaces, computational models and geographic databases (Degroote & Sugumaran, 2010).

3.3.1 Spatial Decision Support Systems for wind farms

Developing projects for the installation of wind farms includes a complex decision making process where several criteria must be analyzed in order to find a suitable location where its most profitable layout can be achieved. For this propose, diverse technological and economic factors must be analyzed to guarantee its profitability, such as wind resources, arrangement of turbines or networks distribution.

Besides, environmental aspects should also be taken into consideration. A common wind turbine has three blades of 30m long which are supported by a tower of 70m height and 4m diameter, resulting in a height of approximately 100m (Ottinger & Bradbook, 2007). The number of turbines per wind farm depends on location and capacity, varying from few to over 100 turbines (Ottinger & Bradbook, 2007). Consequently, the installation and operation phases usually entail negative environmental and social impacts which can be minimized if an adequate study is accomplished.

An Environmental Impact Assessment (EIA) is commonly used for identifying and managing these impacts, being mandatory under certain circumstances. EIA is a procedure which informs the interested parties on the development of a proposed project and its potential consequences on the environment, leading to its approval or rejection (Carroll & Turpin, 2002). The obligation to carry out an EIA is regulated by different laws depending on the country.

The European Directive 97/11/EC (amending the 85/337/EEC) lists all public and private projects for which the European Union always obliges the member countries to implement an EIA and others for which national authorities are the ones responsible of determining whether it is necessary; like “installations for the harnessing of wind power for energy production”.

This directive has been transposed into the national legislation of each member state. For the installation of wind farms in Germany, the EIA Act of 1990 (UVPG, <http://www.gesetze-im-internet.de/bundesrecht/uvpg/gesamt.pdf>) obliges to bring EIA to fulfillment depending on the type, scale and capacity of the project. Furthermore, the German regional authorities demand EIA for projects with more than two turbines greater than 10 MW and also local municipalities for projects with more than one turbine (Wizelius, 2007).

The EIA includes a document called Environmental Impact Statement (EIS) where the technical characteristics of the project, its environmental impacts (including social and cultural), measurements to minimize them and possible alternatives (including different locations) are described.

In conclusion, SDSSs and EIAs can mutually benefit from each other. On the one hand, an EIA includes a quite complete analysis of technological, socio-economic and environmental criteria that should be taken into consideration for developing the regarding SDSS. On the other hand, this SDSS can be applied in the preliminary phases of the EIA in order to facilitate and justify the generation and election of alternatives.

3.4 Overview to the ArcGIS 10 system

ArcGIS 10 is a set of software produced by ESRI for the design and implementation of a complete GIS. These products are:

- **ArcGIS Desktop:** This software allows users to compile, edit, analyze, process and manage geographic data by performing GIS tasks like mapping, spatial analysis or geodatabase management (ArcGIS 10 Help). It includes six different applications (ArcMap, ArcCatalog, ArcToolbox, ModelBuilder, ArcGlobe and ArcScene) and is distributed with three different levels of license which increase in functionality from ArcView to ArcEditor and ArcInfo (ArcGIS 10 Help).
- **ArcGIS Engine:** Includes libraries of GIS components and developer resources to develop custom applications (Bader *et. al*, 2004).
- **ArcGIS Server:** This software allows users to create and manage a serve-side GIS in order to publish maps, geodatabases, models or other geographic contents created with ArcGIS Desktop (ArcGIS 10 Help).

- **ArcGIS online:** Is a free platform for sharing geographic information content from Esri or other users of ArcGIS online, acting like a store hosted in the cloud that can be used to upload, search and download maps, applications or data. This way, any part of the ArcGIS system can access ready-to-use content (ArcGIS 10 Help).
- **ArcGIS.com:** This Web site contains a gallery of maps, Web and mobile applications, as well as communities and workspaces where ArcGIS content can be shared as part of ArcGIS online. Besides, users are allowed to generate mashups by adding the content that has been share, without needing any software installation. (ArcGIS 10 Help).
- **Mobile GIS:** Provides Web access to some mobile devices, being able to access mobile maps or collect, edit and update GIS data in real time (ArcGIS 10 Help). The applications offered by Mobile GIS are map viewing and navigation, data collection and maintenance, and survey (ArcGIS Mobile 10 Help).
- **ArcGIS Explorer:** Users are allowed to open maps, add contents, navigate, extract information and share them with other users. It is available as Desktop and online (ArcGIS Explorer 1500 Help).

ArcGIS Desktop, Engine and Server are built on ArcObjects, a library of software components which can also be combined to develop applications using different programming interfaces, such as COM, .NET, Java and C++ (Bader *et. al*, 2004).

3.5 Automation of geoprocessing with ArcGIS Desktop

Geoprocessing includes any operation to extract, combine or analyze information from an input dataset in order to generate new data (McCoy, 2004). Most GIS software allows geoprocessing input data with the purpose of finding solutions for spatial problems. The GIS platform used for developing this application is ArcGIS Desktop 10, which includes a wide set of tools capable of performing complex spatial analysis. These tools can be applied directly from the ArcToolbox (object containing all geoprocessing tools inside ArcGIS), command line window (where indicating name and parameters of desired tools), ModelBuilder or a script.

ModelBuilder is a graphic modelling development environment included inside ArcGIS with which a sequence of geoprocesses can be created and run automatically, either inside ModelBuilder interface or outside ArcGIS Desktop (if exported to a Python script). The urge of automation appears when a model is demanded to be repeated several times in order to be applied on different datasets or with different parameters. Once the sequence is validated, automation grants a faster and more accurate result than executing the tools manually.

3.5.1 Modeling in ModelBuilder

Models are designed by arranging and connecting input data to the GIS tools that are required to perform a desired spatial analysis. Each generated output can be used as input by another tool, connecting inputs, tools and outputs in a sequence that documents the geoprocessing workflow. As result, the software is able to automatically run this workflow by following those connections.

Most of these tools demand input parameters. For example, if turbines must be installed further than 2 km from natural protected areas, a distance value of 2 km is demanded by the buffer tool in order to derive the areas where turbines cannot be installed. These values can be transformed into model parameters (see figure 2) so that they are asked to be filled by users every time the model is run. Ergo a model without these parameters will always produce the same outcome. Furthermore, although skills in Geoinformatics are needed to develop a model, the parameters make possible for non skilled users to generate different scenarios per model just by changing their values.

ModelBuilder provides an intuitive interface where input and tools can be easily dragged and dropped from ArcMap, ArcCatalog and ArcToolbox; modules of ArcGIS Desktop. A process is formed by a tool and its parameters (e.g. input, output, buffer distance...) and each of them is represented with different symbols (see figure 2). The connection between data and tools generates a workflow representing a visual documentation of the spatial analysis, where rows indicate the direction to follow. Once finished, the model can be exported to a Python script which can be modified in order to extend its functionality.

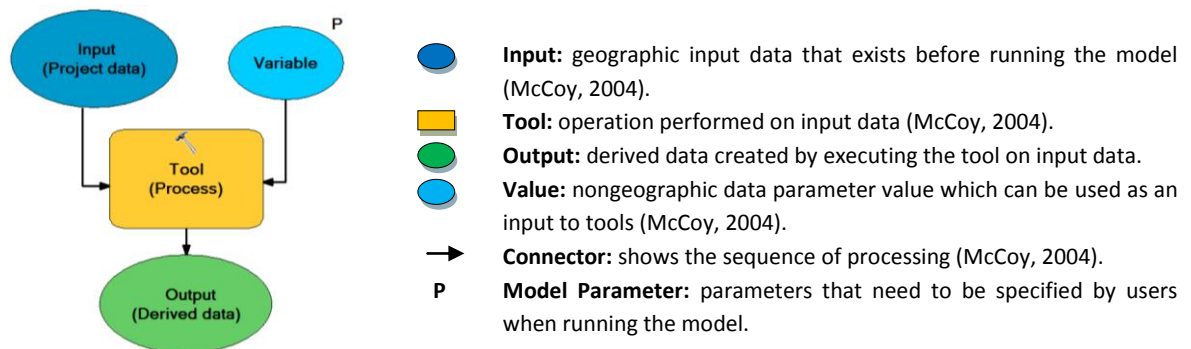


Figure 2: Symbols in ModelBuilder. This diagram shows the typical symbols used by ModelBuilder to represent inputs, variables, tools and outputs.

3.5.2 The functionality of Python

Python is an open source programming language included inside the ArcGIS system that can be used for coding and automating computing tasks, customization of applications or user interface design.

Once a model has been designed in ModelBuilder and exported to a Python script (text files written in a COM-compliant scripting language, such as Python or VBScript (McCoy, 2004)), it can be run as a standalone application. In order to generate different outputs according to input values, the model parameters such as inputs, cell size or workspace are stored as Python's variables which can be modified inside the source code or through a user interface.

Characteristics of Python

This language is object-oriented (constructed with building blocks), extensible (codes can be grown up by adding new blocks that extend the functionality), interpreted (commands can be run automatically via scripting) and embeddable in other languages (making ArcGIS processes scriptable) (Telles, 2008).

Python is composed not only by objects but also classes that determine how to create objects and define their properties (data-members), methods (behavior) and superclasses (behavior to inherit from other classes) (Grayson, 2000). These classes are grouped in modules, which either come already integrated inside Python or have been programmed by other users. If a class is used by a code, the corresponding module must be imported into the script so that the program recognizes the kind of objects that need to be processed. For instance, an ArcGIS function will not run if the module `arcpy` has not been previously imported.

Advantages of using Python

Python is considered among the top five most widely used programming languages in the world today (Lutz, 2011). The advantages are derived from the combination of the easy use of a scripting language and the potential of a complete developer language (Tucker, 2004). Besides, any scripting language that is COM (Component Object Model) compliant interacts well in a Web-based environment, such as Python, VBScript or Jscript (Tucker, 2004). But while Python is supported by multiple platforms (hardware) and operating systems (software), the others are supported only by windows (Telles, 2008).

Moreover, it can be downloaded for free from its homepage (<http://www.python.org/>). Although higher versions already exist, ArcGIS 10.0 only works with Python 2.6. This version is directly integrated inside the ArcGIS installation package, which also includes the Python's editor "IDLE" (Integrated Development Environment). Therefore, once ArcGIS has been installed, any model exported to a Python script can be directly edited without additional software installations.

3.5.3 Graphical User Interface with Tkinter and Tix

The design of a Graphical User Interface (GUI) and its connection to a model exported to Python script allows users to easily interact with the source in order to change the model parameters. In this manner, a “Transparent To The User” (TTU) application can be developed, where users are able to generate different alternatives without programming skills or an understanding in the involved technologies.

GUIs are programmed through toolkits, libraries of controls called widgets which represent visible objects displayed inside the interface; like entries of data, labels, text elements, menus or buttons commanding a certain set of functions (Martelli, 2006).

There are several toolkits for programming GUIs in Python such as Tkinter, PyGtk, PyQt and wxPython. Tkinter has been chosen since according to Lutz (2006, p 367) “is the most widely used GUI toolkit in Python”, “makes it easy to build simple and portable GUIs” and “it can be easily augmented with Python code”. Moreover, Grayson (2000) present some examples showing how Python and Tkinter have been used to develop complex applications.

Tkinter is an object-oriented Python wrapper around the Tcl and Tk programming languages (Martelli, 2006). The main advantages are that it is intuitive, easy to use, extensible and cross platform; being able to run on windows, Macs and Unix (Hammond & Robinson 2000). The first released was in 1990 (Hammond & Robinson 2000) and is included inside the installation package of Python after the version 1.5.2 (Grayson, 2000).

Another important library is Tix, a Tk Interface extension containing user interface components to expand the capabilities of Tcl/Tk and Python applications (<http://tix.sourceforge.net>). It is also an open source software package which is shipped into Python 2.6. on Windows (Lutz, 2006).

3.5.4 Importance of the OS and Arcpy libraries

The libraries OS (operating system) and Arcpy are essential in the development of the desktop application:

- 1) **OS:** According to Lutz (2006, p.92) “os contains variables and functions that map to the operating system on which Python is run.” This library contains the modules required to store and combine the paths which indicates the geoprocessing functions where to find inputs and locate outputs. For example os.path provides the code with an interface to file and directory processing tools (Lutz, 2006).

- 2) **Arcpy:** ArcGIS 10 introduces Arcpy, a site-package to extend the functionality of Python language which includes most of the ArcGIS tools performing geographic data analysis, conversion, management and automation (ArcGIS Help 10). Therefore, if Arcpy is imported into a code, the ArcGIS license will be required to run the script.

Some Arcpy's elements relevant to the desktop application are:

- **Arcpy.sa** (spatial analyst): Module to access the spatial analysis functionality of ArcGIS.
- **Arcpy.mapping:** Module that allows the automation and manipulation of map documents and layer files as well as export and printing of maps.
- **Env:** The Arcpy's class "env" is used to determine environment settings like cell size, processing extend or workspace. Besides, it allows geoprocessing functions to overwrite existing outputs.

3.6 Raster and vector formats

There are two basic types of spatial data: vector which represents discrete features as points, lines or polygons, and raster where features are represented in a grid of uniform cells where each cell contains an assigned value creating a continuous surface of data. Which one to choose depends on the characteristics of the data and the purpose for which a GIS will be used (Gregory & Ell, 2007).

On the one hand, vectors are normally used for human features, precise well-known features (Gregory & Ell, 2007), clearly bounded entities and network analysis (Wheatley & Gillings, 2002). On the other hand, rasters are comely used for environmental systems, when there is uncertainty in data (Gregory & Ell, 2007), no clear boundaries and when there is a need of overlay, comparison and combination of locations within thematic layers (Wheatley & Gillings, 2002).

3.7 Fuzzy logic

In contrast to classical logic where only true and false values are allowed to indicate the fulfillment of a statement, fuzzy logic distributes degrees of truth or falsehood in order to model imprecise situations.

ArcGIS 10 incorporates two new overlay tools (Fuzzy Membership and Fuzzy Overlay) using a fuzzy logic which transforms expert semantic descriptions to numerical spatial models in order to predict locations (Raines *et.al*, 2010). For example, the statement "the further the wind farm is from natural protected areas, the more suitable is its location", can be processed with the tool fuzzy membership which performs a linear transformation on a raster of distances, assigning maximum suitability to the furthest areas and decreasing until the closest areas which are assigned minimum suitability.

3.8 ArcGIS Server

ArcGIS Server is a platform for delivering enterprise GIS applications and services with the purpose of sharing GIS functionality and resources throughout the Internet, such as maps, tools or geodatabases (ArcGIS Resource Center). Thus, the network connection of a GIS resource created with ArcGIS Desktop and published into the server allows clients to remotely access the ArcObjects which provides the GIS services (ArcGIS Resource Center).

As in any server technology, the data is centrally managed, clients are provided with the most up-to-date data, and multiple users are supported. In addition, ArcGIS Server includes advanced GIS functionality and is built on industrial standards (Bader *et.al*, 2004).

3.8.1 The ArcGIS Server system architecture

ArcGIS Server is characterized by a multi-tier architecture which contains the data server, the GIS server, the Web server and the clients. According to ArcGIS 10 Help:

- **Data server:** Once a GIS resource has been authored by ArcGIS Desktop applications, it is stored in the data server and transformed to GIS services by their publication on the GIS server.
- **GIS server:** Is composed by a Server Object Container (SOC) and a Server Object Manager (SOM). The SOC is in charge of hosting the GIS resources which run on the server and are managed by the SOM. Thus, when a client application sends a request to the server, the SOM identifies the required services in the SOC so that the server can provide clients with the desired services. The GIS server is also connected to the ArcCatalog administrator that allows its usage as well as the administration of its properties and services.
- **Web server:** The GIS Server and the clients communicate with each other through Web applications and services hosted in the Web server. While Web applications are designed for human consumption, Web services are intended for machine consumption, being used by other services or applications (Toma *et.al*, 2011).

This server is further connected to a Manager administrator in charge of the publication of GIS resources, administration of the GIS server and creation of Web applications.

- **Clients:** GIS clients can be Web browsers, mobile devices or desktop clients such as ArcMap or ArcGIS Explorer. Any GIS client connected to the network is able to request the published GIS services.

3.8.2 Publication of geoprocessing services

This thesis focus on the publication of a geoprocessing model developed with ArcGIS Desktop 10, although ArcGIS Server is also able to provide other different types of services such as map, geocode, geodata, image or search services (Desktop 10 Help).

A geoprocessing service consists on tasks that are created by publishing geoprocessing models or script tools, either publishing geoprocessing toolboxes or map documents containing tool layers (ArcGIS 10 Help). Thus, this GIS service provides a collection of published tools for the analysis and manipulation of geographic data that Web clients can request through the Internet or an intranet. Once the request is sent, the server executes the tool inside the server computer and sends back the corresponding outputs to the clients.

In consequence, automation of geoprocesses can be designed in ArcGIS Desktop and share over the Internet, allowing thin clients to perform heavy spatial analysis. Besides, the geoprocessing service can be used not only in Web applications, but also by ArcGIS Desktop and Explorer (Desktop 10 Help).

3.8.3 Web application

According to Wang *et al.* (2012, p.221) “The web application server acts as a bridge that connects web clients to the spatial operation and analyzing functions of ArcGIS Server”. ArcGIS Server 10 provides with a Server Manager, two Application Developer Frameworks (ADFs) and three Application Programming Interfaces (APIs) for the creation of Web applications.

The Server Manager allows the creation and edition of Web mapping application, as well as the development of a basic interface for the communication client-server. Additionally, two ADFs built on .NET or Java are provided in case that the functionality of the Web applications developed on the Manager are not enough. According to Wang *et al.* (2012, p.221) and ADF is a “standards-based set of components for building and deploying geospatial applications and services”, allowing the creation and customization of applications. Furthermore, ArcGIS Server 10 includes three APIs; Javascript, Silverlight and Flex. An API is a set of interfaces, methods, protocols, tools and templates for the creation and customization of software programs (Server 10 Help).

Selecting the most suitable depends on several factors such as nature of the services, characteristics of the client or developers’ skills.

4. LITERATURE REVIEW

4.1 GIS for site selection of wind farms

At the beginning, only Digital Elevation Models were used to find suitable locations for wind farms because of the great influence that the topography has on their profitability (Domínguez & Amador, 2007). Indeed, GIS were used only to perform simple spatial analysis with overlay and buffer, acquiescing a limited evaluation of the selected areas (Hansen, 2005).

Since then, the analysis has become more and more complex; from a study including only buffer distances to settlements, water bodies and historical areas (Baban, 2001), to projects with several technological and environmental variables developed in Spain (Ramirez-Rosado *et al.*, 2008) and Turkey (Aydin *et al.*, 2010), until deep multi-criteria analysis with ArcGIS 10 (Haaren & Fthenakis, 2011).

In addition, other software have been developed to analyse the Environment, having applications in wind farm sitting. For instance, Insensa-GIS is a new free open source software for GIS data processing and statistical analysis realised in 2011. It has been developed for index construction and sensitivity analysis, including statistical analysis of GIS data, development of weighted indices, testing of the robustness of created indices, display and export of results (Biber *et al.*, 2011). Although it has not been specifically designed for wind farms sitting, it could have applications in this field.

4.2 SDSS for site selection of wind farms

Domínguez & Amador (2007) mention five DSS based on GIS designed for renewable energy integration in Europe (REGIS, EPURE, EnTRACK, REPLAN and REDES). Each of them designed for different criteria and purposes. They also remark that many projects apply GIS technology for solving localization decision problems in the field of renewable energy.

Ramirez-Rosado *et al.* (2008) propose a DSS implemented on a GIS platform for helping in the selection of new wind farms locations. They remark that most of the DSS have been designed including economical, technical, environmental and social criteria. They also name the use of GIS in different DSSs that have been successfully implemented and specify the advantages of its spatial calculation and visualization capabilities.

4.3 Web based GIS for site selection of wind farms

The number of studies related to Web based GIS for the site selection of wind farms is limited. Maria *et al.* (2011) designed a GIS-based DSS consisting on a Web based freely accessible Wind Resource Mapping System (WRMS) in order to assist public operators in the preliminary location of wind farms. It was developed using open sources; MapServer (for building the application) and p.mapper (for developing a user-friendly interface) using Java and PHP/Mapscript. They noticed the low number of interactive GIS-based WRMS available on the Web, especially the freeware.

Sun *et al.* (2011) mention that “the existing geospatial information network services still have some limitations”, such as poor interaction user-application and services more concentrated on the server side, wasting the possibilities offered in the client side.

5. AIMS & OBJECTIVES

Aim

To develop two GIS based Spatial Decision Support Systems to assist users in the preliminary site selection of wind turbines without a need of understanding the involved technologies; the first one as a desktop application adaptable to any kind of wind energy project and the second one as a Web application specific for the State of BW to fulfil the requirements of LUBW.

Objectives

- To create a model that automates the geoprocessing workflow needed to generate different alternatives of location according to the input data and variables.
- To program the code generated with ModelBuilder in order to make all inputs optional.
- To build a user friendly interface that improves the one provided by ModelBuilder, allowing users to easily insert and modify those variables without a need of knowledge in the involved technologies.
- To design an Internet architecture that allows the decision makers to access the SDSS via Internet.

6. RESEARCH QUESTIONS & HYPOTHESIS

Research questions

1. Is the user capable of finding the most suitable location of wind farms without directly manipulating the GIS behind?
2. Are the variables and criteria (specified in section 7) which are planned to be included in the model adequate and sufficient to find the most suitable location for wind farms?
3. Does the automation of the process affect the quality of the results?

Hypothesis

Hypothesis 0: A SDSS can be implemented.

Hypothesis 1: All tools used in ArcGIS have inputs that can be easily accessed through a user interface without opening the software.

Hypothesis 2: On the one hand, the criteria included in the desktop application includes the most common parameters analyzed by the EIAs for wind farms' sitting. Consequently, they are enough to find the most suitable locations for any project related to wind exploitation. On the other hand, the criteria established by the UM are adequate and enough for them. However, this SDSS is designed as a simplified preliminary site selection for political use and it cannot be used as a detailed EIA which requires more criteria and weights reflecting their importance.

Hypothesis 3: Combination of the proposed software (specified in section 7) allows the automation of complex geoprocessing workflows getting the same results as if manually processed.

7. DATA, HARDWARE & SOFTWARE

7.1 Data

The data used to develop and test both SDSSs are delimited to the State of BW and they have been provided by the LUBW and the UM. All the data were created between 2009 and 2011 by German public institutions using the projected coordinate System DHDN/ 3-Degree Gauss-Kruger Zone 3, suitable for Germany. They are given as ArcGIS file geodatabase (format for storing GIS data in ArcGIS).

- ❖ **Wind resources:** Wind atlases at 100 and 140 meters height given as vector (polygon shapefiles) and raster, representing wind resources as speeds at those heights.
- ❖ **Land use:** one polygon shapefile containing hamlet areas.
- ❖ **Water:** one polygon shapefile containing superficial water bodies.
- ❖ **Roads:** two linear shapefiles containing Federal and State roads.
- ❖ **Railways:** one linear shapefile containing railways' infrastructure.
- ❖ **Natural Protected Areas:** thirteen polygon shapefiles containing natural areas with different levels of protection.

The DTM of Baden-Württemberg was obtained from Prof. Dr.-Ing. Schröder Dietrich in order to generate slopes.

7.2 Hardware

ArcGIS Desktop and Server 10.0 have been used for the development of the SDSSs. The minimum hardware requirements specified by them as well as the characteristics of the computer where they have been developed are listed in the table 3.

Table 3: Hardware requirements.

Requirement	Minimum requirements	Computer used
CPU speed	2,2 GHz	2,0 GHz *
Processor	Intel Pentium 4, Core Duo or Xeon Processors	Intel Core i7
RAM	2GB	6GB
Disk Space	2.4 GB	500 GB
Screen Resolution	1024 x 768	1366 x 768
Display Properties	24 bit color depth	64 bit
Video/Graphics Adapter	64 MB RAM	Nvidea 540 MB

* Although the CPU speed is slower, the processor has greater MPIS (capacity of processing) than the Intel Core Duo, not generating any problem during the development.

7.3 Software

- **Operating system:** While the desktop application has been developed on Windows 7 Home Premium, an upgrade to Ultimate has been required to develop the Web application.
- **Desktop GIS:** ArcGIS Desktop 10.0 has been used for its capability to manipulate great amounts of spatial data and the inclusion of:
 - **ModelBuilder:** Applied to develop and test the models with which the SDSSs have been programmed. ModelBuilder allows the automation of workflows with model parameters which can be easily modified by the users in order to generate different outputs for a same model. Besides, it is capable of exporting the workflow to a Python script, which can be further programmed to make all the inputs optional.
 - **Python 2.6:** Suitable for the product customization and user interface design.
 - **ArcMap 10:** Used for testing the models before programming the rest of the architecture, as well as for the creation of a map document required to allow the Web clients to access the geoprocessing functionality and to visualize the generated outputs inside the Web application.
 - **ArcCatalog 10:** Allows rapid access to the databases, geoprocessing tools and models.
- **Database:** All the data have been given inside an ArcGIS file geodatabase, which can be scalable if needed and allows fast performance.
- **ArcGIS Server 10:** This software is able to host and publish models designed with ModelBuilder as well as Python script tools. Besides, it supports multi-access and includes tools for spatial data management, analysis and geoprocessing. It also provides an environment for the publication of web applications and GIS services, making them accessible through the Internet.

8. METHODOLOGY

In order to achieve the purposed objectives, the thesis has been divided in four phases:

- A. Design and development of the SDSSs in ModelBuilder.
- B. Development of a desktop application with Python and Tkinter.
- C. Development of a Web application with ArcGIS Server.
- D. Thesis writing.

A general overview of the steps followed to achieve the aim of the thesis is given in the next section. Besides, a description of the methodology applied to each phase is explained from the section 8.2 to the section 8.5. Additionally, a detailed description about how the models, the desktop and Web applications have been developed is included in their corresponding sections 9.1 ModelBuilder, 9.2 Desktop application and 9.3 Web application.

Finally, the section 11 Time Schedule shows the schedule that was suggested during the proposal of the thesis as well as the final duration of the phases and the reasons of the needed modifications.

8.1 General overview

The Development of the SDSSs starts with the documentation and selection of the main criteria involved in a decision making process for the site selection of wind farms. Once the conceptual design has been developed, these criteria must be processed to identify the suitable locations.

Although the required spatial analysis can be performed manually in ArcGIS Desktop, the analysis must be documented as a model in ModelBuilder and certain model parameters must be defined in order to achieve automation. In this manner, the users are able to automatically generate different alternatives of location without manipulating the ArcGIS software.

Furthermore, the functionality of ModelBuilder must be extended because this application obliges to process all the source data (ArcGIS Help 10), while the number of inputs in a site selection project will depend on the users' requirements and the characteristics of the project. Therefore making the inputs optional is essential.

Finally, the desktop and Web applications can be developed. For the desktop application, a user friendly interface needs to be implemented in order to allow the users to modify the model parameters without directly editing the source code. For the Web application, a modification of the models must be performed in order to be able to publish them in the Server, since not all the data types supported by ArcGIS Desktop are also supported by ArcGIS Server (ArcGIS Help 10). Then, a web application must be created to allow the clients to easily communicate with the server and request the GIS services.

8.2 Phase A: Design and development of the SDSSs.

1. **Specifications of LUBW:** Meetings with LUBW in order to obtain the data and design the SDSS according to their needs and specifications. *Outcome:* The requirements are:
 - Development of the spatial analysis in ModelBuilder in order to automatically process the requested data. The number of criteria has increased during the thesis period (see section 10).
 - Make all the inputs optional.
 - Development of a Graphical User Interface to execute the models from the desktop, modify model parameters and indicate the users the reduction of the suitable areas after the restrictions are applied.
 - Publication of the models in ArcGIS Server.
 - Development of a Web application, preferable with the API for Silverlight.
2. **Literature review:** Further research about wind energy development projects, Environmental Impact Assessments and related technologies. *Outcome:* Better understanding of the characteristics required by a general SDSS for the site selection of wind farms and the potential users' needs.
3. **Learning of related technologies:** Including spatial analysis of vector and raster data as well as its automation with ModelBuilder. *Outcome:* Capacity to automate the geoprocessing workflows.
4. **Geoprocessing model design:** Creation of the workflows to automatically perform the spatial analysis required by the DSSs. Methodology:
 - To find, organize and connect the adequate geoprocessing tools in ModelBuilder.
 - To select and create the model parameters necessary for the generation of different alternatives of location by running the same model with different input values.
 - To test and evaluate the functionality and suitability of each model by carrying out a site selection for the State of BW.
 - To export the complete model to a Python script in order to extend its functionality and be able to run it outside ArcGIS. ArcGIS license is still required since the python library "arcpy" from ArcGIS has been imported into the code.

Outcome: Three geoprocessing workflows (models) have been designed to automatically perform the spatial analysis required by both SDSSs. The first one has been designed exclusively for LUBW and the other two have been developed in order to test their performance in the distribution of suitability weights for the desktop application.

8.2 Phase B: Development of the desktop application

1. **Literature review:** Further research about Python in ArcGIS, GUI programming toolkits, Python modules and libraries. *Outcome:* Selection of Tkinter for the development of the GUI for the desktop application. First of all because Tkinter is included inside Python 2.6 which comes inside the installation package of ArcGIS Desktop 10.0, therefore users do not need additional software installation. Besides, Tkinter provides a suitable platform for the development of the application.
2. **Learning of related technologies:** Including Python 2.6, Arcpy, Tkinter package and other modules required to extend the functionality of Python such as tix, os, ScrolledText, tkMessageBox or tkFileDialog. *Outcome:* Capacity to develop the GUI without installing additional software. Therefore only ArcGIS Desktop 10.0 is required since Python 2.6 and the rest of imported modules are already included inside its installation package.
3. **Graphical User Interface Design:** Design of two GUIs, one to test the Python code programmed for LUBW before publishing the application in ArcGIS Server and the other to access the desktop application. *Outcome:* Two GUIs programmed with arcpy module, Python 2.6 and the mentioned modules. The first GUI allows the selection and modification of all the inputs and model parameters required by LUBW. Its appearance has not been given special importance since its aim is to test the code. The second GUI is a user friendly interface where the inputs and model parameters can be easily changed. It contains an intuitive structure with images, colours, help menus and other elements explained in more detail in section 9.2.
4. **Functional Graphical User Interface Programming:** Connection of the models with their corresponding GUIs. Methodology:
 - To program the codes generated with ModelBuilder so that they can be combined with the codes of the corresponding GUIs, allowing the model parameters to get the values inserted by users in the interface as well as making the results accessible to the users.
 - To test the application.

Outcome: Successful modification of the model parameters through the interfaces without editing the source code. For testing, the criteria included within the interfaces have been classified into sections which have been independently tested. Besides, all the vector and raster data have been clipped with the boundaries of Stuttgart in order to test the GUIs by performing a small wind farm site selection in the region of Stuttgart.

8.3 Phase C: Development of the Web application

1. **Specifications of LUBW:** The application is intended to be developed in ArcGIS Server 10 for .NET platform with the API for Silverlight. *Outcome:* Upgrade of the operating system to Windows 7 Ultimate in order to fulfil the software requirements of ArcGIS Server 10. The Internet Information Services (IIS), a web service for Windows required in the installation of ArcGIS Server for .NET, could not be successfully installed and consequently .NET was replaced by the Java platform (see the section 9.3 Web application).
2. **Literature review:** Further research about ArcGIS Server 10 and the development of web applications. *Outcome:* Awareness of the different possibilities provided by ArcGIS Server for the development of Web applications.
3. **Learning of related technologies:** Including the preparation of GIS services for their publication in ArcGIS Server 10 for Java and the development of Web applications with Server Manager. *Outcome:* Capacity to publish map and geoprocessing services as well as the development of simple web applications.
4. **Development of the Web application:** Methodology:
 - To prepare the models for their publication.
 - To publish them In ArcGIS Server 10.
 - To create a Web application with Server Manager.

Outcome: Web application providing the geoprocessing of the model for LUBW with the same functionalities as ModelBuilder.

9. OUTCOMES

9.1 ModelBuilder

Three different spatial analyses for the identification of suitable locations have been automated with ModelBuilder, connecting the inputs with the appropriate tools and in the sequence required to obtain the desired outputs.

The section 9.1.1 explains the purpose of each model. The section 9.1.2 describes the models's design and the Annex I includes a detailed description of the spatial analysis performed by each model. Besides, an example of a site selection in the State of BW has been carried out in order to compare the three models, explained in the section 9.1.2.

9.1.1 Purpose of the designed models

Three different models have been designed with the following objectives:

- **First model:** The first model has been developed according to the demands of LUBW as a political tool of assessment in the installation of wind turbines in the State of Baden Württemberg.

The tool has been designed in order to allow the users to identify the suitable wind resources within the State and reject those located on restricted and protected areas, being the environmental constrains the predominant criteria. Thus, the final output will indicate the areas where the wind speeds are profitable and no restrictions have been found.

As a request of LUBW, this model has been designed to be tested in the desktop trough a simple Graphical User Interface (GUI) and later modified for its publication in the Server.

- **Second and third models:** They include the most common criteria analyzed by the Environmental Impact Assessments (EIAs) of wind farms in order to be applicable to any kind of project for the site selection of wind turbines.

These models select the areas where the technical requirements assure the profitability of the wind farm and reject those located on restricted and protected areas. Besides, each analyzed criterion adds a percentage of suitability to the final suitable areas, reflecting their importance in the final site selection.

When these models are executed, the users are asked to introduce a percentage or weight for each criterion. This weight is then assigned to the suitable areas but with two different approaches. For the second model, all the suitable areas received the full weight. For the third model, the weight is assigned with the fuzzy membership tool of ArcGIS, being distributed proportionally to how much they fulfill the suitability criteria indicated by the users.

For example, a minimum distance from settlements is applied in order to avoid negatives impacts such as noise or visual impact. The three models will extract the settlements and their surroundings from the final suitable areas.

Additionally, the users decide to increase in 10% the weight of those areas outside settlements. While the model 2 would assign the weight 10 to all these areas, the model 3 would assign a value 0 to the boundaries, increasing the weight until 10 in the furthest areas. Hence, the minimization of the impacts with the distance is considered only by the third model.

Therefore, the final outputs of the models 2 and 3 will not only indicate the areas where the exploitation of the wind farm is profitable and no restriction has been found but they will also classify the suitable areas by percentage of suitability. Both have been designed to be accessed as a desktop application through a GUI.

9.1.2 Description of the models' design.

The source data that are used as input to a model as well as some parameters required by the tools have been defined as model parameters. In this manner, every time a user executes a model, a dialog opens asking the users to indicate the inputs and other values such as the suitable wind speeds or a minimum distance from settlements. Thus, each model is automatically executed generating different alternatives according to the input criteria. A list of the created model parameters is given in Table 4.

Due to the dimensions of the models, they have been subdivided into submodels in order to facilitate their analysis, management, correction and reuse as scripts during the applications' programming. Therefore each criterion is processed by an independent submodel. A detailed description of the spatial analysis performed for each submodel is given in the Annex I.

Table 4: Created model parameters. Summary of the criteria and inputs demanded to the users per submodel and model.

	Submodel	Model	Included	Inputs demanded to users
Technical requirements	1. Wind resources	1	Yes	2 vectors, 2 SQL expressions
		2 & 3	Yes	4 rasters, 4 where clauses, 4 weights
	2. Slopes	1	No	No considered
		2 & 3	Yes	1 DTM, 1 value of slope (expression), 1 weight
	3. Roads	1	No	2 vectors, 2 distances
		2 & 3	Yes	2 vectors, 2 SQL expressions, 4 distances, 2 weights
	4. Power lines	1	No	No considered
		2 & 3	Yes	1 vector, 1 SQL expression, 1 distance, 1 weight
Abiotic impacts	5. Railways	1	No	No considered
		2 & 3	Yes	1 vector, 1 distance, 1 weight
	6. Land use	1	Yes	1 vector, 1 distance
		2 & 3	Yes	6 vectors, 6 SQL expressions, 6 distances, 6 weights
	7. Water bodies	1	Yes	1 vector, 1 distance
		2 & 3	Yes	2 vectors, 2 SQL expressions, 2 distances, 2 weights
	8. Restricted or protected areas	1	No	No considered
		2 & 3	Yes	5 vectors, 5 SQL expressions, 5 distances, 5 weights
Biotic impacts	9. Natural protected areas	1	Yes	13 vectors, 13 distances
		2 & 3	Yes	6 vectors, 6 SQL expressions, 6 distances, 6 weights

Combination of submodels

After the spatial analysis has been designed and tested it for each criterion, they are combined to complete the entire model. The symbology used by ModelBuilder is explained in figure 3.

Model 1 (figure 4): First of all the submodel of Wind resources is processed in order to identify suitable areas. Then the outputs of the following submodels are erased from these areas one by one with the aim of calculating the reduction in suitable areas after each restrictive criterion is applied (calculated with the tool “Summary statistics”).

Model 2 and 3 (figure 5): The desktop application has been designed for any kind of project related to wind farms; therefore the nature and characteristics that the input data will have at the moment of geoprocessing are unknown. For this reason, first of all the submodel of wind resources is processed and the cell size and processing extend of its output will be use by the rest of submodels (this is explained in detail in the Annex I).

Since the model 3 can be considered as a variant of the model 2, the combination of all the submodels follows the same structure. All their outputs are added by the “Raster calculator” tool in order to eliminate the restricted areas and add the suitability weights of each criterion. Afterwards other tools are applied to indicate the users the area of the final suitable locations (this is also explained in detail in the Annex I).

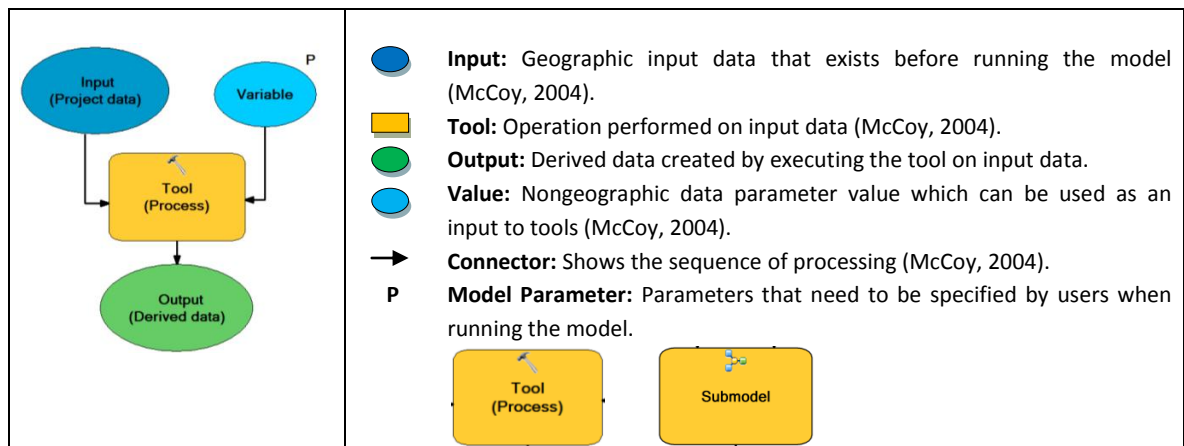


Figure 3: Symbols used inside the models.

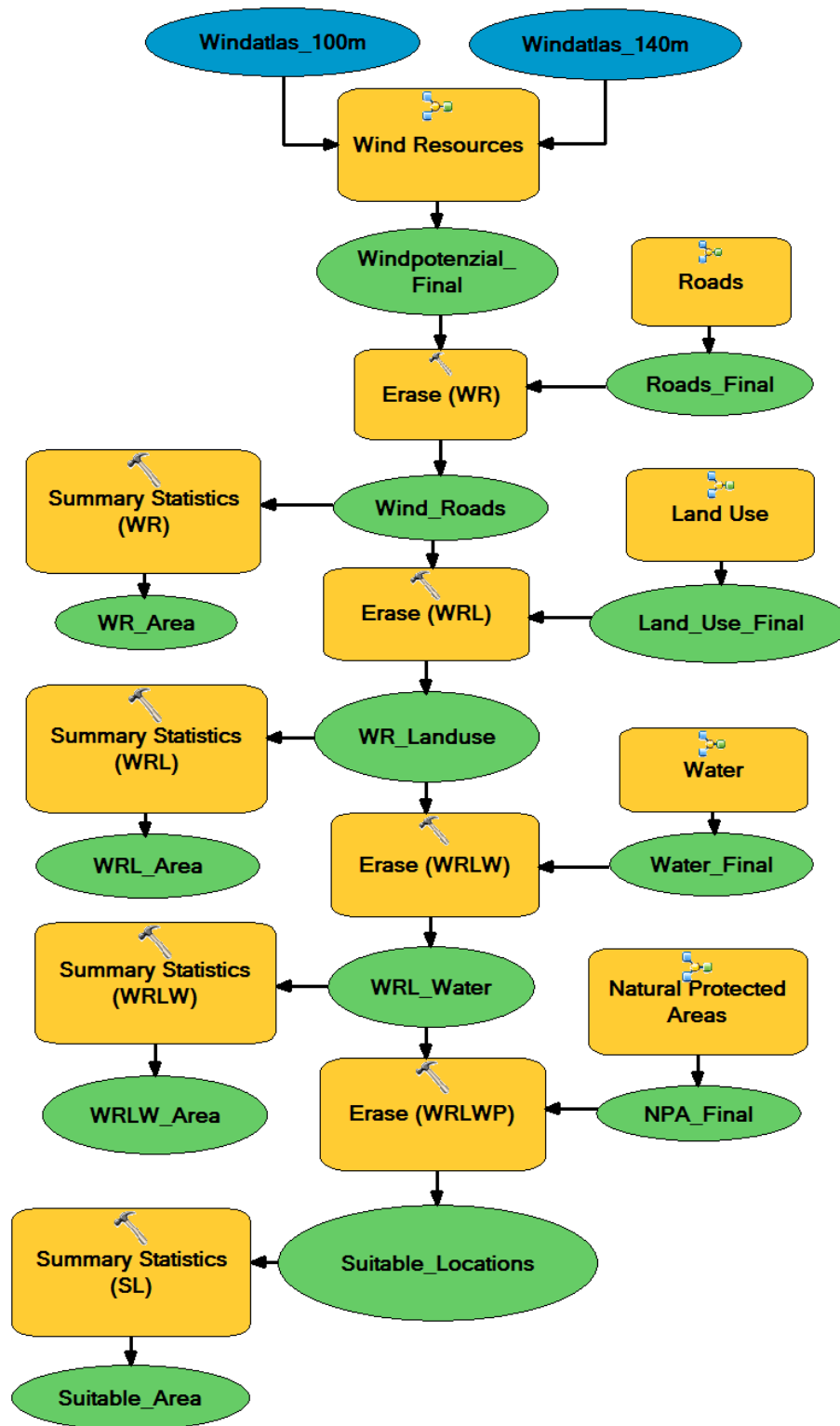


Figure 4: Complete model 1. Combination of all the submodels to generate the entire model 1.

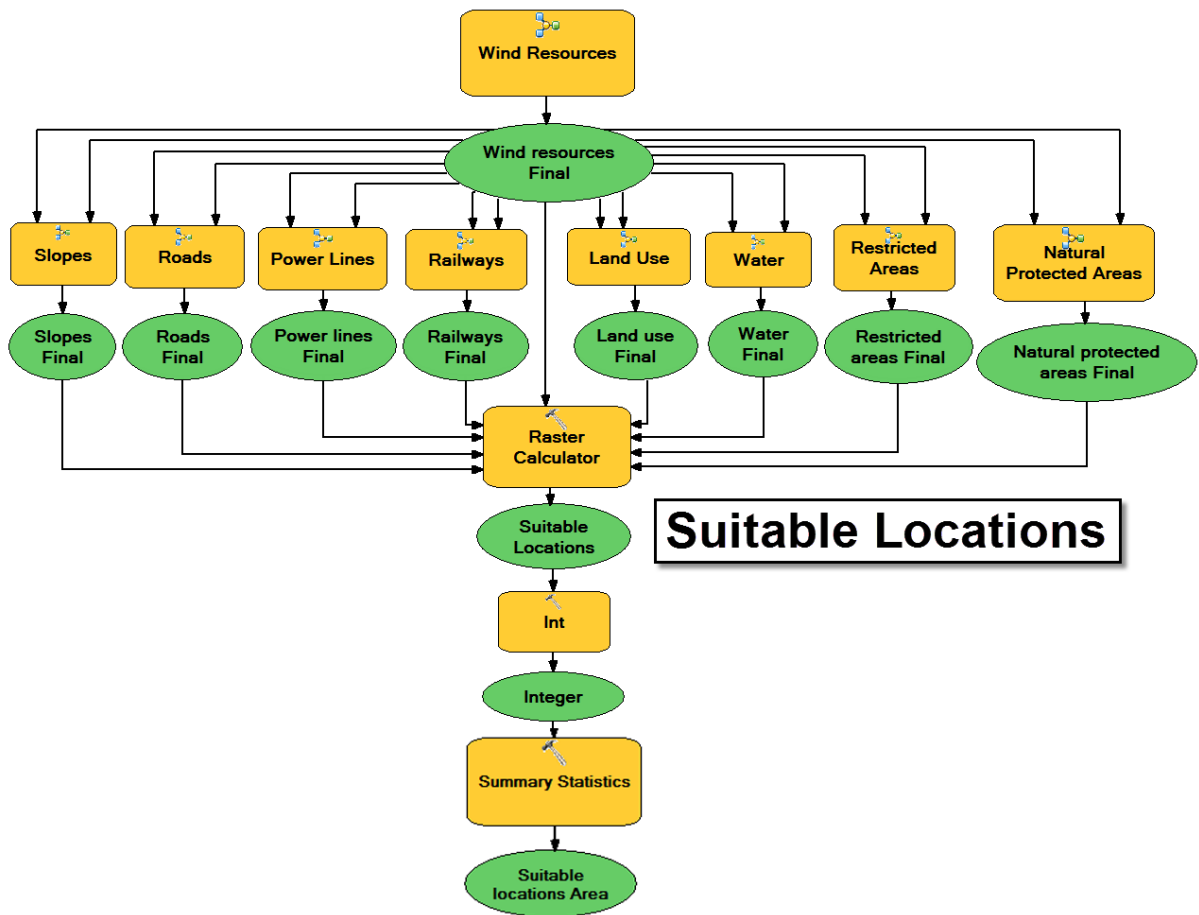


Figure 5: Entire model 2 and 3. Combination of all the submodels to generate the entire models 2 and 3.

9.1.4 Comparison of the models: Test applied in the State of BW

In order to perform a comparison between the three models, an imaginary project for the site selection of a wind farm in the State of Baden Württemberg has been carried out, processing criteria according to the available data. The processed criteria as well as the assigned weights (applied for model 2 and 3) are listed in Table 5.

The grade of importance for each criterion will depend on the geographical area where the wind farm is planned to be installed as well as the criteria of the decision makers. Actually, the distribution of weights entails a long and deep analysis of the area of study and the characteristics of the projects. Since the development of a methodology for the distribution of weights is not part of the scope of the thesis, a logical but random distribution has been applied.

On the other hand, the minimum distances from restricted or protected areas have been applied taking into consideration the values established by the Regional Plan of the Donau-Iller region (Table 7). Additionally, the times of geoprocessing demanded by each model are specified in the Table 6.

Table 5: Criteria and weights. Summary of criteria and weights (applied only to model 2 and 3) included in the site selection process of a wind farm performed in the State of Baden Württemberg in order to compare the three different models designed in ModelBuilder for the development of the two SDSS.

Criteria	Weight
1. Wind resources:	40
▪ At 100 m height	Speeds from 4,5 to 5,49 m/s 5
	Speeds from 5,5 to 15 m/s 15
▪ At 140 m height	Speeds from 4,5 to 5,49 m/s 5
	Speeds from 5,5 to 15 m/s 15
▪ Rest of wind speeds	erased
2. Slopes:	3
▪ Slopes	Slopes smaller than 17° 3
	Slopes equal or greater than 17° 0
3. Infrastructure (roads):	12
▪ Federal roads	Distance within 150 m erased
	Distance between 150 and 25000 m 7
	Distance outside 5000 m 0
▪ State roads	Distance within 150 m erased
	Distance between 150 and 5000 m 5
	Distance outside 25000 m 0
4. Infrastructure (railways):	3
▪ Railways	Distance within 150 m erased
	Distance outside 150 m 3
5. Land Use:	15
▪ Settlements	Distance within 450 m erased
	Distance outside 450 m 15
6. Water:	6
▪ Water 1 st Order	Distance within 150 m from 1 st Order erased
	Distance outside 150 m 6
7. Natural protected areas	21
▪ SPA	Distance within 1000 m erased
	Distance without 1000 m 7
▪ Nature reserve	Distance within 200 m erased
	Distance without 200 m 7
▪ Forest reserve and protective forests	Distance within 200 m erased
	Distance without 200 m 7
Total weight:	100

Table 6: Speeds of geoprocessing for selected criteria. Comparison of the times required to fulfill the geoprocessing of the three models. First, time for each criterion and addition of times for all the criteria is listed. At the end of the table, time required to run complete models is indicated.

Criteria	Model	Time of processing
1. Wind resources:	1 LUBW	4 min 30 sec
	2 No Fuzzy	2 min 25 sec
	3 Fuzzy	3 min 33 sec
2. Slopes:	1 LUBW	No considered
	2 No Fuzzy	43 sec
	3 Fuzzy	1 min 15 sec
3. Infrastructure (roads):	1 LUBW	1 min 27 sec
	2 No Fuzzy	20 min 04 sec
	3 Fuzzy	29 min 49 sec
4. Infrastructure (railways):	1 LUBW	No considered
	2 No Fuzzy	2 min 12 sec
	3 Fuzzy	3 min 44 sec
5. Land Use:	1 LUBW	1 min 30 sec
	2 No Fuzzy	37 min 43 sec
	3 Fuzzy	1 hour 02 sec
6. Water Bodies:	1 LUBW	22 sec
	2 No Fuzzy	42 sec
	3 Fuzzy	2 min 57 sec
7. Natural protected areas:	1 LUBW	22 sec
	2 No Fuzzy	8 min 30 sec
	3 Fuzzy	12 min 31 sec
Addition of times:	1 LUBW	8 min 11 sec
	2 No Fuzzy	1 hour 15 min 19 sec
	3 Fuzzy	1 hour 50 min 51 sec
Complete models:	1 LUBW	21 min 45 sec
	2 No Fuzzy	1 hour 20' min 10 sec
	3 Fuzzy	2 hour 01 min 24 sec

Project scenario: An imaginary company plans to install 6 wind turbines of the model ENERCON E-70 E4 in the State of Baden Württemberg. The considered technical characteristics given by ENERCON GMBH (2012) are:

- Power unit: 2,30 MW.
- Possible Hub heights: 57 m / 64 m / 85 m / 98 m / 113 m
- Minimum wind speed: 2,5 m/s
- Maximum wind speed: 28 -34 m/s

Wind resources are planned to be exploited at 100 and at 140 meters height, consequently the possible hub heights have been adapted to force the turbines to exploit wind resources at those heights. These resources must fulfill a serial of technical, economical and environmental criteria whose grade of importance depends not only on the characteristics of the project and the area where it is planned to be implemented, but also on the criteria of the persons involved in the decision making process.

9.1.2.1 Wind resources:

As shown in the power curve of the model E-70 E4 in the figure 6, these turbines start to generate electricity at 2,5 m/s (cut-in speed) and reach the maximum power delivery at 16 m/s (rated wind speed). In order to avoid possible damages in the system, the turbines are brought to a standstill when the wind speeds reach around 28 - 34 m/s.

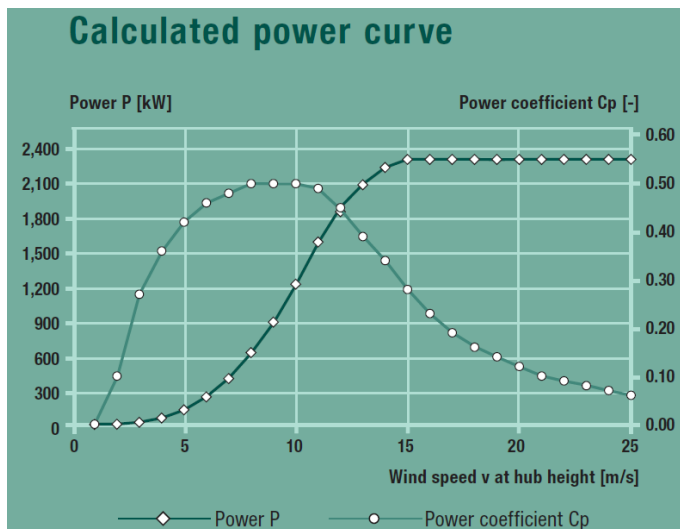


Table copied from ENERCON GMBH (2010, pag.10)

Cut-in speed: wind speed at which turbines start to deliver useful power (Manwell et.al, 2009).

Rated wind speed: wind speed at which maximum power output of the electrical generator is produced (Manwell et.al, 2009).

Cut-out speed: maximum wind speed at which turbines are allowed to produce power because of safety constrains (Manwell et.al, 2009).

Wind [m/s]	Power P [kW]	Power coefficient Cp [-]
1	0.0	0.00
2	2.0	0.10
3	18.0	0.27
4	56.0	0.36
5	127.0	0.42
6	240.0	0.46
7	400.0	0.48
8	626.0	0.50
9	892.0	0.50
10	1,223.0	0.50
11	1,590.0	0.49
12	1,900.0	0.45
13	2,080.0	0.39
14	2,230.0	0.34
15	2,300.0	0.28
16	2,310.0	0.23
17	2,310.0	0.19
18	2,310.0	0.16
19	2,310.0	0.14
20	2,310.0	0.12
21	2,310.0	0.10
22	2,310.0	0.09
23	2,310.0	0.08
24	2,310.0	0.07
25	2,310.0	0.06

Adaptation of a table from ENERCON GMBH (2010, pag.10)

Figure 6: Technical specifications E-70 E4. Calculated power curve shown as graphic (above), shown as table (right) and description of technical terminology of interesting points in a power curve (below).

Therefore, it would be convenient to perform two selections of suitable speeds for each height, the first one from the cut-in speed (2.5 m/s) until the rated wind speed (16 m/s) and the second one from here until the cut-out speed (28 m/s), giving greater importance to the second selection which

represent the maximum production of energy. But since the available data contains speed values until 12 m/s, the company has agreed a first selection from 4.5 to 5.49 m/s (weight 5) and a second selection from 5.5 to 12 m/s (weight 15). Consequently, a total weight of 40 has been assigned to wind resources since it is the most important criterion for this company.

The input data are two wind atlases representing wind speeds at 100 and 140 m height above ground, introduced as vector for model 1 and as raster for models 2 and 3.

Analysis:

Time of geoprocessing: Completion of the model 1 takes almost the double than model 2 although the spatial analysis is simpler and no weights are included. The reason behind is the input format and the number of entities which have a direct impact in the performance of the model.

Two vector shapefiles were given as input by LUBW: The wind atlas at 100 m represents the wind speeds with 210425 polygon features and the wind atlas at 140 m which stores 147013 different polygons. Consequently the geoprocessing is much slower than when the data are processed as raster format, which is more appropriate for wind resources since they represent continuous data where all the regions contain wind speeds.

On the other hand, the model 3 takes around one minute more than both models, rational because of the major complexity and length of the designed workflow.

Accessible information: After processing wind resources with model 1, the output indicates a high availability of suitable wind resources in the region of BW (see figure 7), especially at 140m height, since wind speed usually increases with the height.

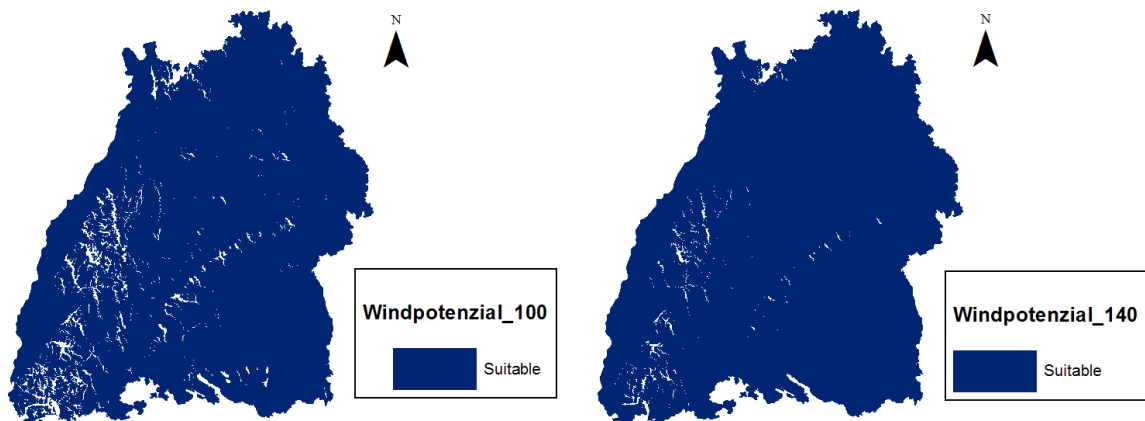


Figure 7: Selected wind resources for model 1. These vectors show the areas containing suitable wind resources (dark blue) selected according to the inserted SQL expression, at 100m (left) and 140m (right) height.

The model 2 processes two different selections for each wind atlas (at 100 and 140m); one selection from 4.5 to 5.49 m/s which obtains a weight of 5 and a second selection from 5.5 to 12 m/s which is assigned a weight of 15.

As shown by the figure 8, the first range of speeds is more abundant at both heights in comparison to the second range which contains a higher kinetic energy and is able to produce more electrical power. Therefore, if a large wind farm was planned to be developed, the best choice would be to install turbines at 140 m. The main reason is the major potential energy production, but also because wind atlas 140 m shows more numerous big continuous surfaces than in the case of wind atlas 100 m. But since this project only implies 6 turbines, the available surface does not seem to be a critical factor at any of those heights as long as no big environmental constrains or restrictions reduce dramatically the surface.

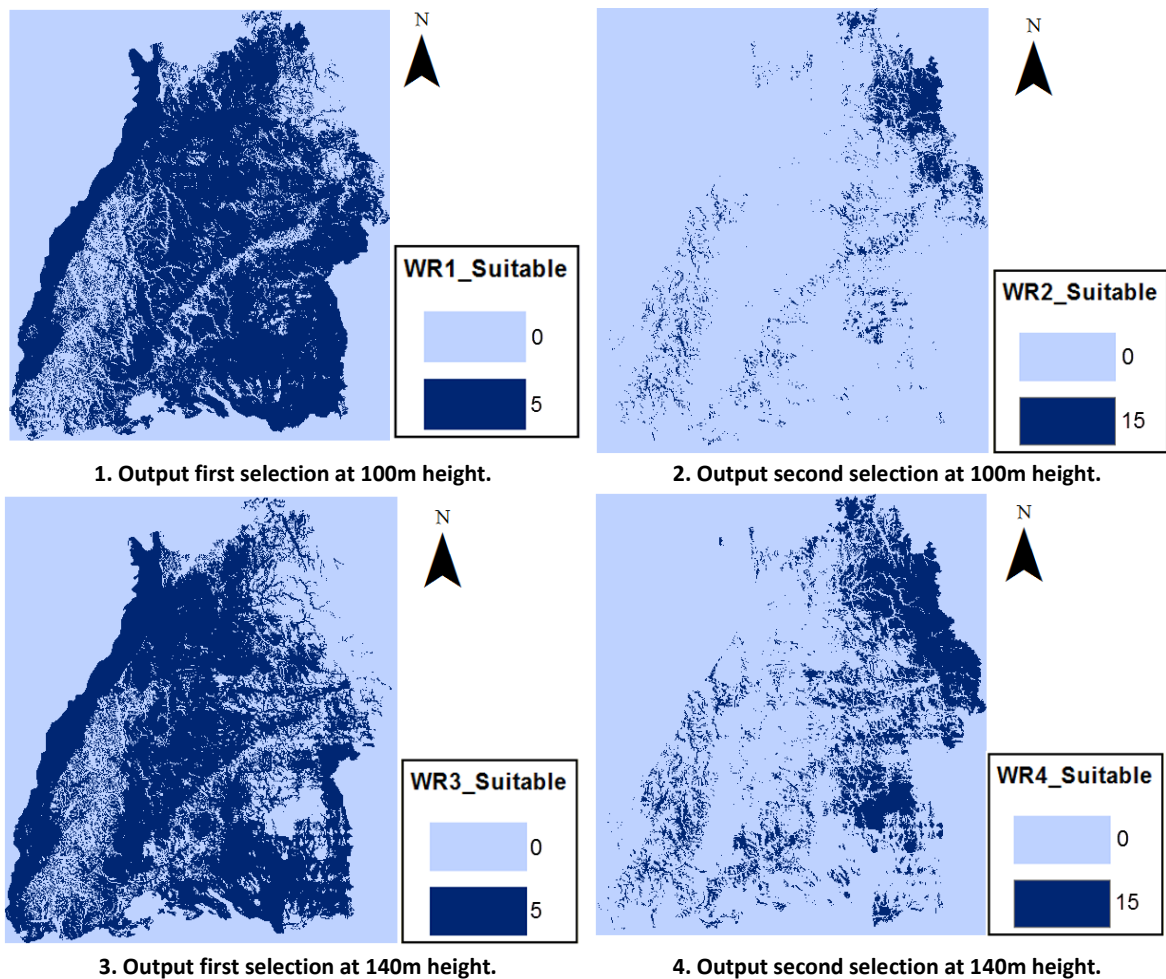


Figure 8: Selected wind resources for model 2. These rasters show the suitable areas carrying their corresponding weight (dark blue), selected according to the inserted where clause. Four selections have been performed; first (top left) and second (top right) ranges of speed at 100m (left) and first (bottom left) and second (bottom right) ranges of speed 140m. Areas with no selected resources are represented as light blue.

The model 3 is a modification of the model 2 where the weights are distributed according to wind speed; the higher the speed, the greater the weight. Although the resources are the same for both models (see figure 9), more information can be extracted from this output. For example, the highest selected speeds, which represent maximum profitability, are gathered in relatively small areas. Consequently, if they are planned to be exploited, the wind farm's dimension becomes a critical factor. Another example, three suitable areas for the exploitation of resources at 140m stands out for their dimensions and profitability (see figure 10). These three areas will be compared with the rest of criteria introduced by each submodel.

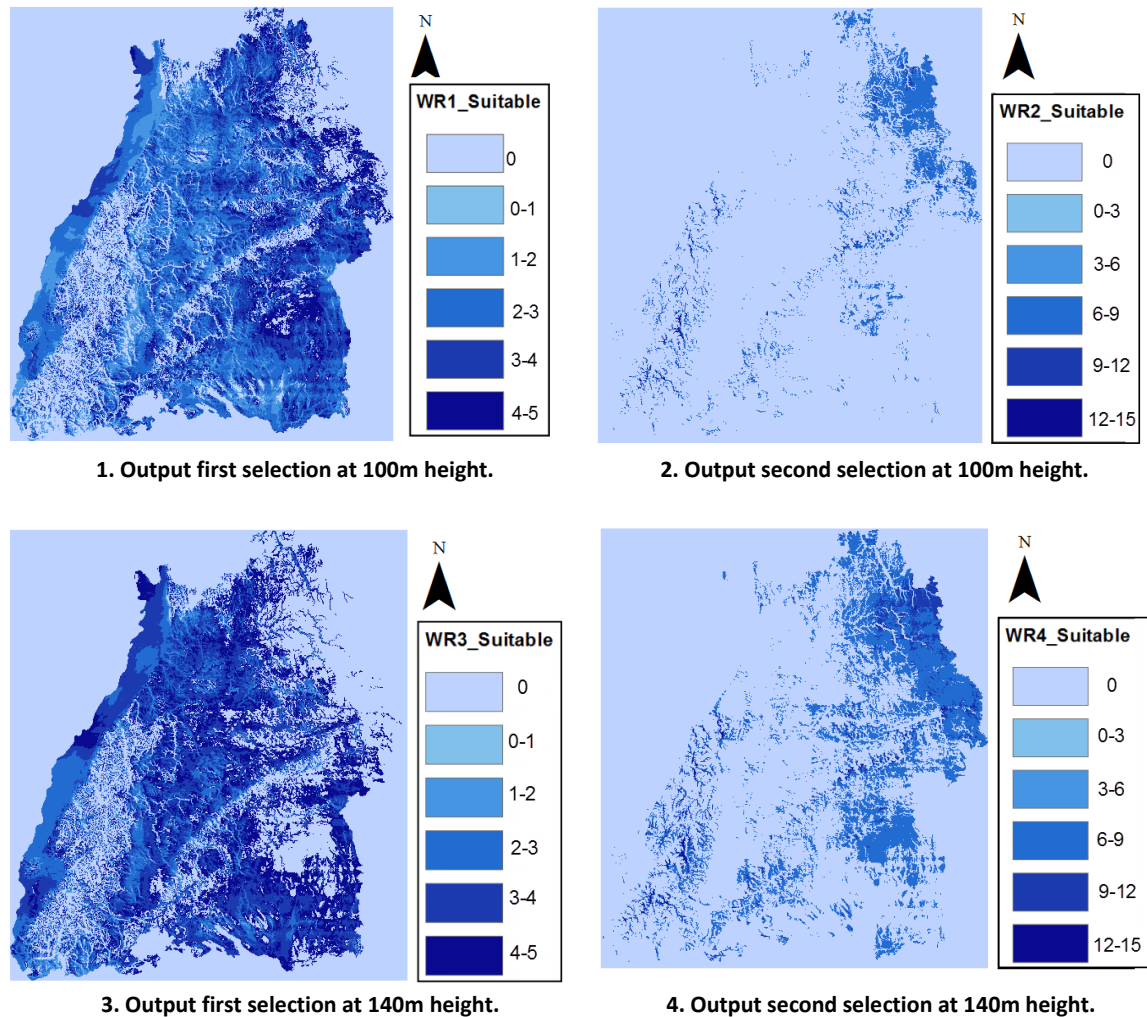


Figure 9: Selected wind resources for model 3. These rasters show suitable areas selected according to the inserted where clauses. Four selections have been performed; first (top left) and second (top right) ranges of speed at 100m (left) and first (bottom left) and second (bottom right) ranges of speed 140m. Weights have been assigned with fuzzy membership. The darker the cell the more suitable the area is within the raster. Areas with no selected resources are represented with the lightest blue.

The quantity of final resources is identical for the three models (see figure 10), since the same speeds have been selected. But while they appeared represented by the same value in model 1 (because no weights are assigned); the models 2 and 3 represent the different additions of all the weights accumulated in each cell. If all the suitable speeds are fulfilled in a cell, the possible maximum weight is 40; ergo Baden-Württemberg does not contain all the considered resources in the same location.

Furthermore, while the weights between 10 and 20 predominate in the output of model 2, areas with a weight between 5 and 10 are more abundant in model 3. This is a direct consequence of the fuzzy membership tool of the model 3 where the full weight is distributed proportionally to wind speed, a difference from the model 2 where all the selected speeds receive automatically the full weight.

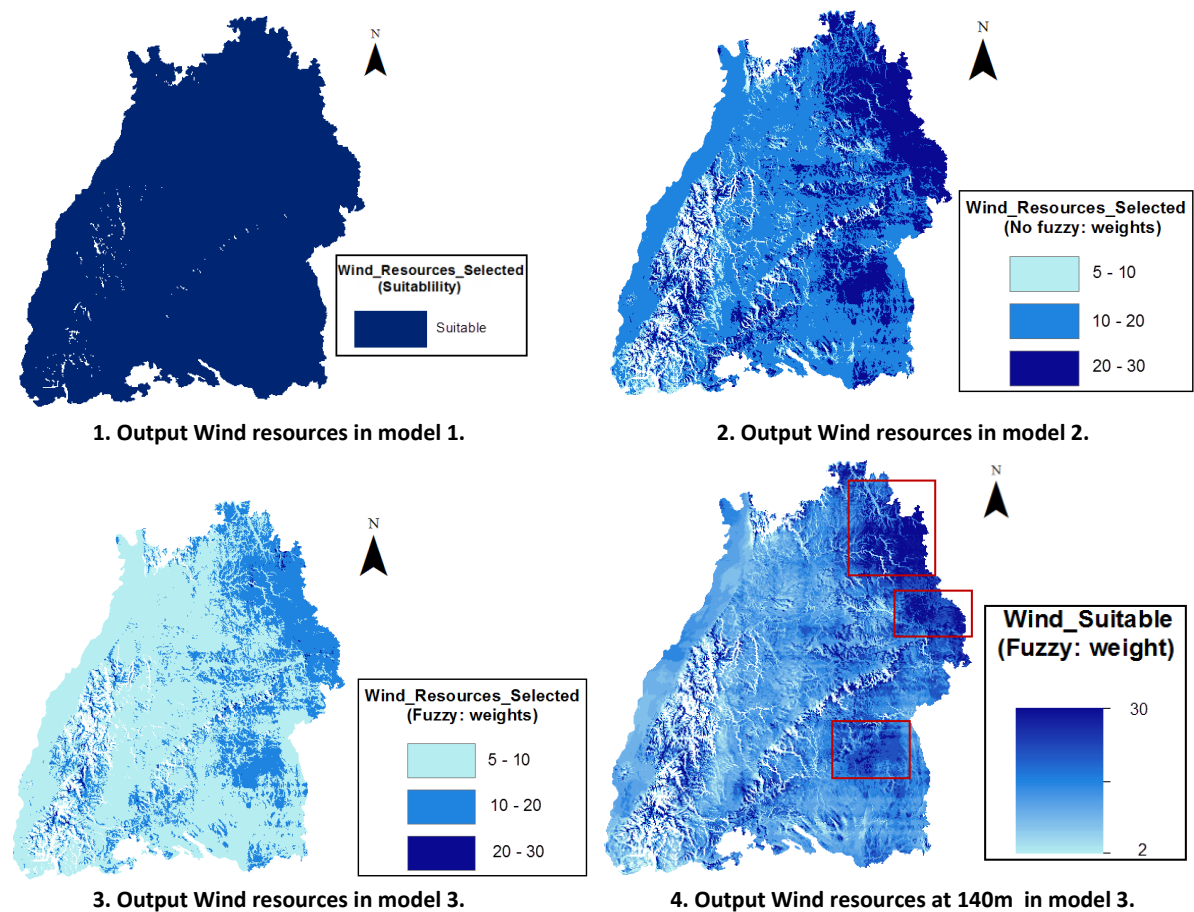


Figure 10: Results from Wind resources models. Selected wind resources for model 1 (above) are represented as suitable areas in vector format. Wind resources for models 2 (bottom left) and 3 (bottom right) are represented as different weights of suitability in raster format.

9.1.2.2 Slopes:

BW is characterized for a relatively flat terrain and consequently slopes are not a critical criterion. Therefore the company has decided to increase the suitability of areas in only a 3% and for slopes smaller than 17°, for which turbulences are not likely to appear and a small movement of land is only required during the assembling of turbines.

Analysis:

Time of geoprocessing: Model 1 does not include this criterion, ergo only the models 2 and 3 have been processed. Model 3 takes almost double time than model 2 because of a greater number of tools implicated in its processing.

Accessible information: As seen in the figure 11, all the slopes in BW are suitable since they are smaller than 17°. The model 2 assigns them full weight, while model 3 assigns the maximum weight to slopes of 17° and decreases to 0 for the smallest slopes in the region, which in this case is 0°.

In addition, the model 3 indicates that the most suitable areas are located mainly in the west and east borders of the State. Combining this information with the one derived from wind resources' models, the north east part of BW would be an appropriate area for the installation of turbines.

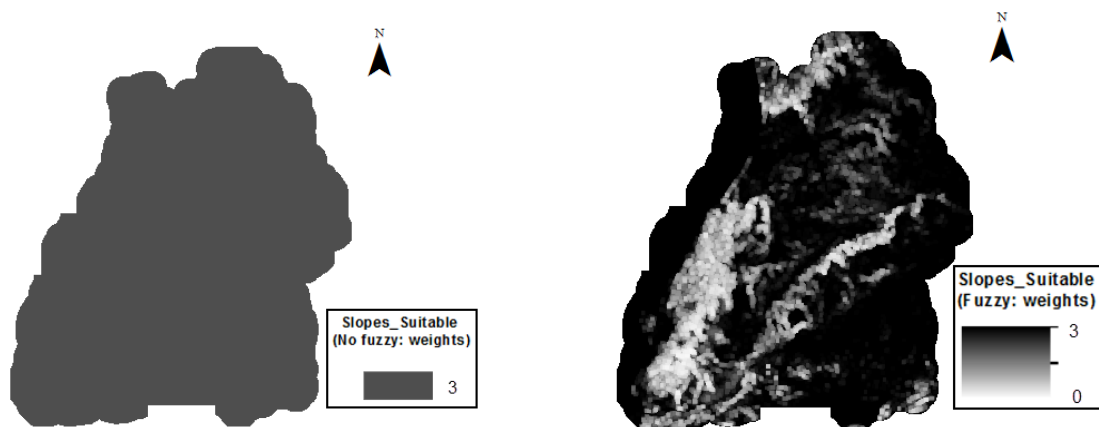


Figure 11: Results from Slopes models. Selected slopes for models 2 (left) and 3 (right) are represented as different weights of suitability in raster format. This criterion is not taken into account in model 1.

The remaining criteria has been applied taking into consideration the criteria established in the Regional Plan of the Donau-Iller region (Table 7), which statement of obligation is published in the Government Gazette of Baden-Württemberg (Staatsanzeiger für Baden-Württemberg Nr. 49 vom 18. Dezember 2009). The geoprocessing has been done according to available data.

Table 7: Criteria established in the Regional Plan of the Donau-Iller region. *The original plan is in German language, a translation is found inside the brackets. Source: Table translated from the Staatsanzeiger für Baden-Württemberg Nr. 49 vom 18. Dezember 2009.*

Ausschlussflächen (Excluded areas)	Berücksichtigter Abstand (m) (Considered distance)	Available
Siedlungsflächen (settlement areas):		
▪ Wohnbauflächen (residential areas)	700	No
▪ Gemischte Bauflächen (mixed built areas)	450	No
▪ Siedlungssplitter und Einzelgehöfte (settlement and isolated farms)	450	Yes
▪ Industrie- und Gewerbeflächen (industrial and commercial areas)	250	No
Freizeit- und Siedlungsgrün (Leisure and residential):		
▪ Freizeit und Erholungseinrichtungen, die meist zu längerem Aufenthalt angelegt sind (leisure and recreation facilities for long stays)	700	No
▪ Grünanlagen und Friedhöfe (parks and cemeteries)	450	No
▪ Siedlung für Erholung und Fremdenverkehr (settlements for recreation/tourism)	700	No
Infrastruktureinrichtungen (Infrastructure):		
▪ Autobahnen (Highways)	150	No
▪ Bundes-, Landes- und Kreisstraßen (Federal, State and County roads)	150	Yes
▪ Bahnlinien (Railway lines)	150	Yes
▪ Verkehrsflughäfen, Verkehrslandeplätze (airports, airfields)	1000	No
▪ Kabelfreileitungen (cable lines)	100	No
Rohstoffsicherung (protected raw materials)		
▪ Sicherung von Rohstoffvorkommen (nur Vorranggebiete) (securing mineral deposits)	30	No
Naturschutz (conservation):		
▪ Vogelschutzgebiete der EU (important bird area of the EU)	1000	Yes
▪ Bestehende und geplante Naturschutzgebiete (existing/planned conservation areas)	200	Yes
▪ Biotop aus Umweltbericht Rohstoffe (biotope environmental natural resources)	30	No
(Grund-) Wasserschutz ((ground) water)		
▪ Wasserschutzzonen I (water protection area 1)	50	No
▪ Gewässer 1. Ordnung (water bodies of 1st order)	150	Yes
▪ Übrige Fließgewässer (other streams)	10	No
▪ Binnengewässer >0,5 ha (internal waters > 0,5 ha)	150	No
Wälder (forests)		
▪ Bannwälder (protective forests)	200	Yes
▪ Schonwald (forest reserve)	200	Yes
▪ Besonders geschützte Biotop nach Landeswaldgesetz (special protected Biotop according to the state law)	200	No

9.1.2.3 Roads:

Areas within a distance smaller than 150 m have been erased from all the models because of security reasons. The models 2 and 3 include an additional criterion. Once a minimum distance is guaranteed, the closer a wind farm is to the existing suitable roads, the less budget is invested in creating new infrastructure. Consequently, the company has given an additional weight to areas between 150 and 5000 m, weight 7 for Federal roads and 5 for State roads. The areas further than 5000 m are not of special interest, so they have been assigned value 0.

Analysis:

Time of geoprocessing: Although the input data are the same for the three models (two shapefiles with linear features), there is a great difference in the times of processing due to differences in their complexity and length. For instance, while the first model processes data with only 6 tools, the processing in the other two models requires 30 and 38 tools respectively.

Therefore, if the decision makers were only interested in minimizing safety risks, the first model would be the best choice since it is the fastest.

Accessible information: In this case there is no difference in the number of selected roads since although the models 2 and 3 allow the selection of roads according to their characteristics, all of them have been included. Ergo the three models generate the same areas to exclude (see figure 12).

As in the previous criteria, the output generated with fuzzy membership shows fewer areas with higher values than the model 2, which will add more suitability in the final site selection. The three outputs are represented in the figure 13 including a zoom into a concrete area.

Figure 14 displays the selected roads and their surroundings on the output from Wind Resources of model 3, displaying three zooms in large areas where the high wind speeds promise a profitable production of energy. As observed, although the selected roads divide these territories, they do not considerably decrease the suitable areas. Besides, the roads are normally built between hills, where the wind speeds are less appropriate. Since this project plans to install only 6 turbines, the resulting areas seems to be big enough and the most suitable resources are close to an appropriate transportation network.

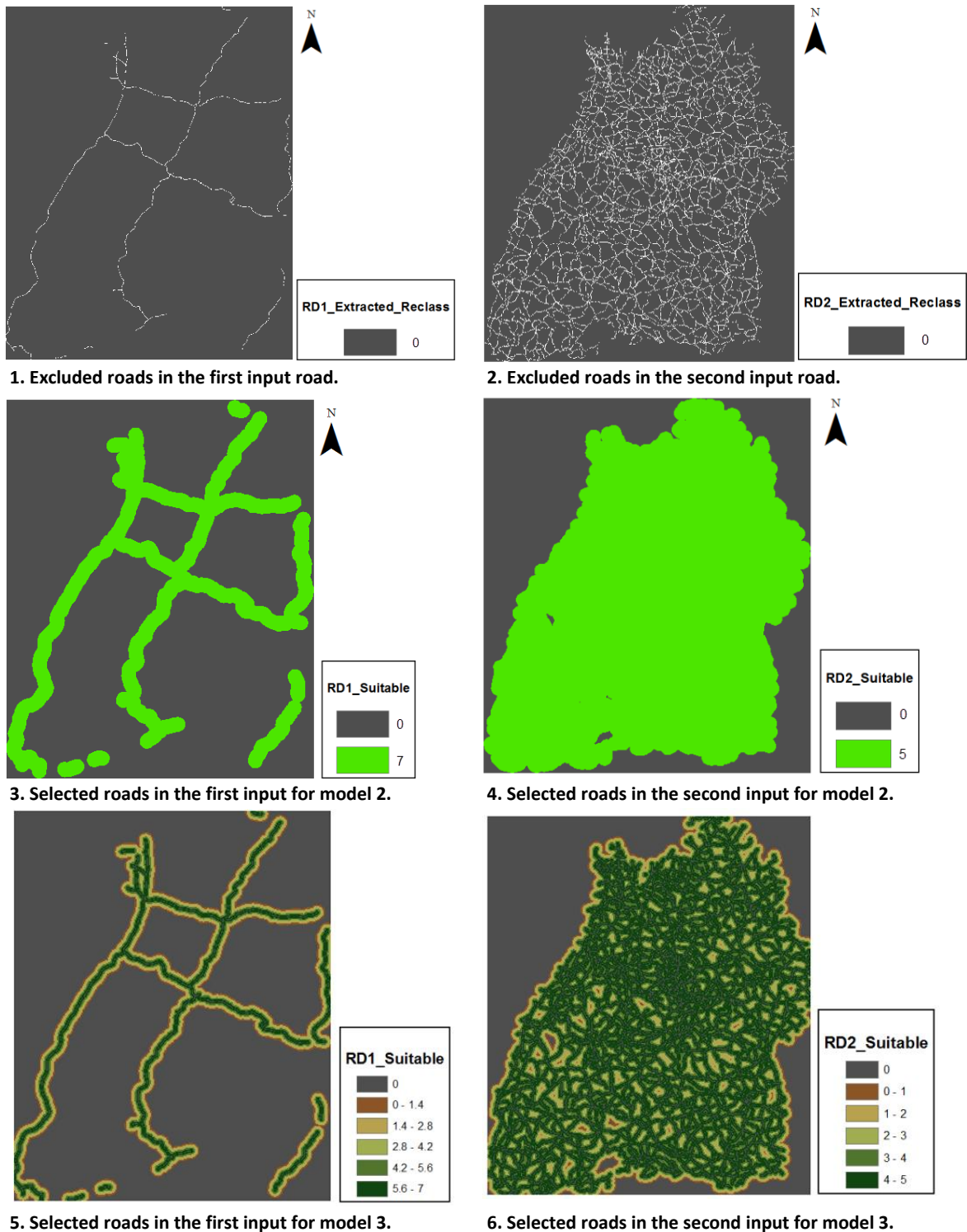


Figure 12: Selections and exclusions of Roads models 2 and 3. Each input vector generates two rasters. One contains areas to exclude (1&2, the same for both models) where roads are reclassified as NoData. The other represents selected suitable roads containing the assigned weights i.e. 7 for Federal roads (3&5) and 5 for State roads (4&6). Model 2 assigns full weight to selected roads (3&4), while model 3 distributes weights proportionally to distance (5&6).

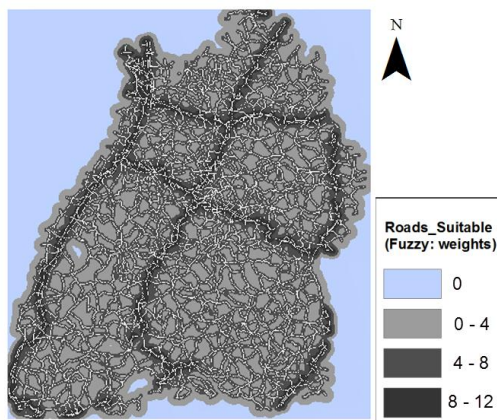
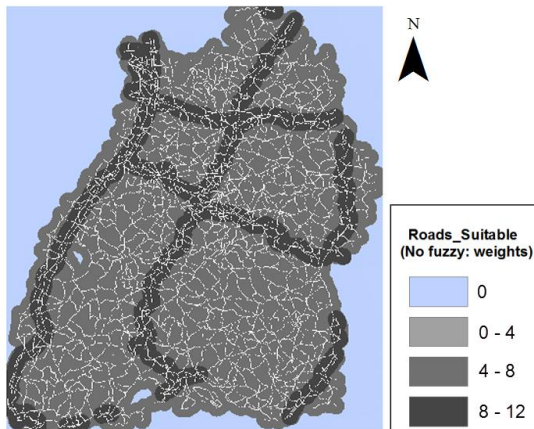
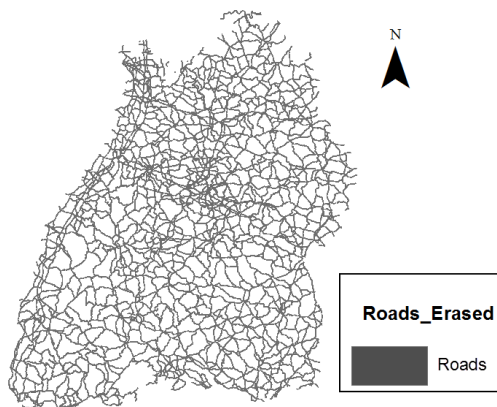


Figure 13: Results from Roads models Combination of all input criteria generates three different outputs, a vector for model 1 (1 & 2) containing roads to exclude, and two rasters for model 2 (3 & 4) and 3 (5 & 6), containing roads to extract as NoData and distribution of weights.

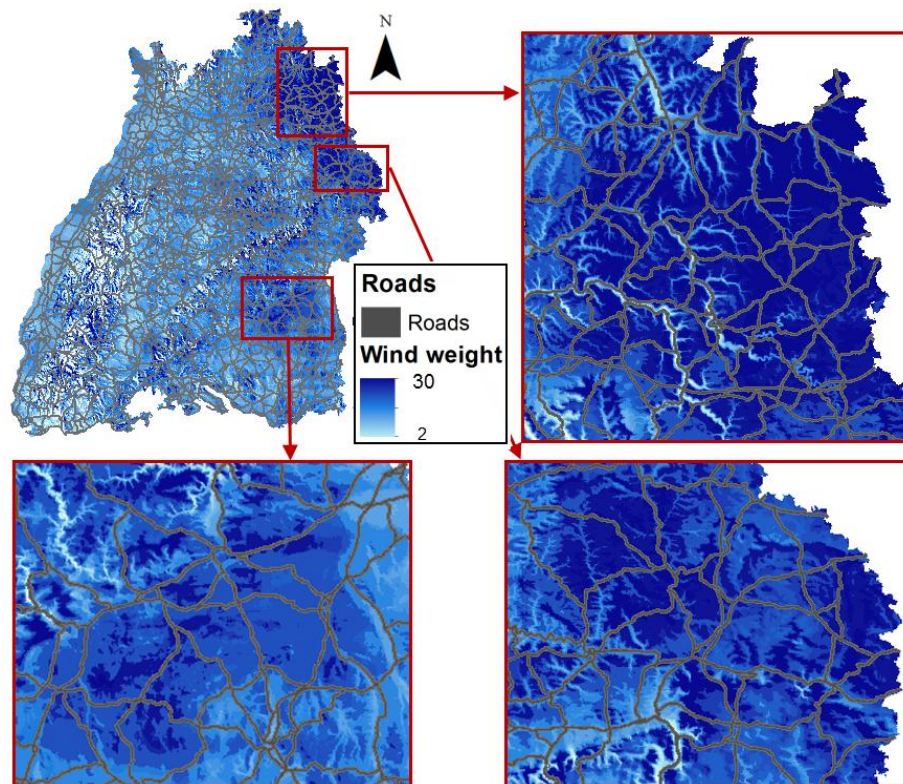


Figure 14: Relation Wind resources and Roads. This image represents three zooms in the output of Wind Resources in model 3 where roads have been displayed on.

9.1.2.4 Power lines: This criterion has not been processed because no data was provided.

9.1.2.5 Railways:

The site selection of model 1 does not include this criterion. For the others, the areas within a distance smaller than 150 m have been erased because of security reasons. Further areas have been assigned a weight of 3, which is distributed proportionally to the distance in model 3, representing the decrease of visual impact (for the passengers in transit) with the distance.

Analysis:

As in the previous criteria, the model 3 requires a longer time of processing and shows a clear uniform classification of weights: The further the area is from railways, the higher is its weight (see figure 15).

There are four areas with high density of railways and although they are far away from the most suitable wind resources (see figure 16), still some railways are within the proximity of the three areas that seems to be the most suitable for the company until now. Therefore, the model 3 does not assign them full weight.

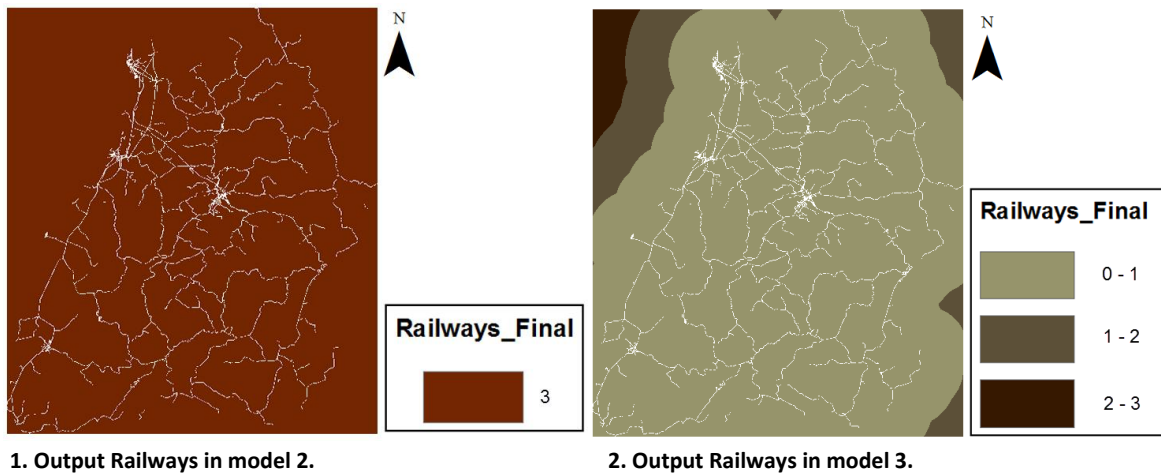


Figure 15: Results from Railways models. White lines contain NoData and represent railways and buffered area to exclude in the final selection. Image on the left shows output of model 2 where all the suitable areas contain weight 3. In contrast, model 3 (on the right) shows a proportional distribution of weights according to the distance.

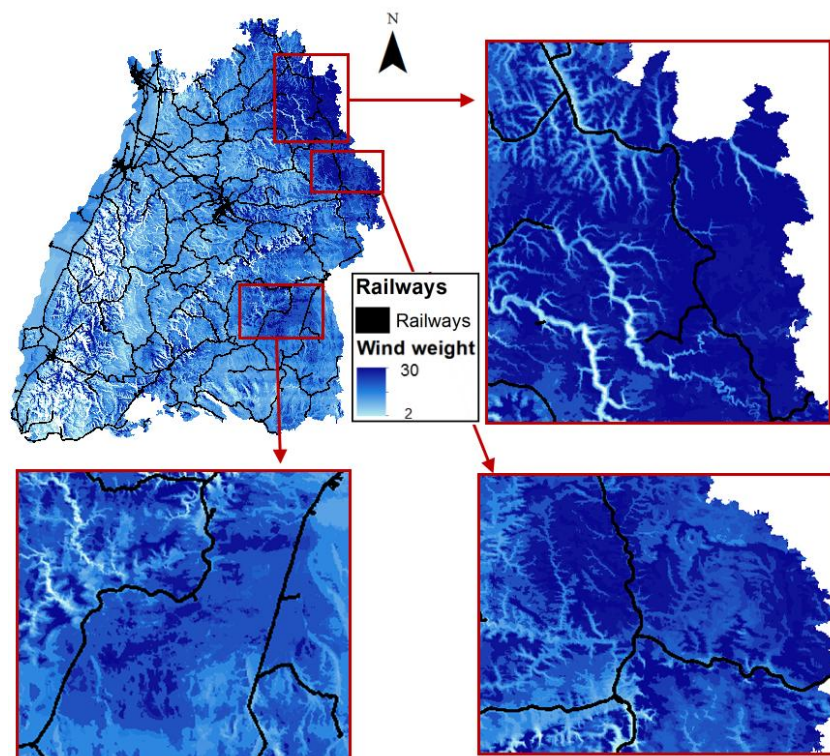


Figure 16: Relation Wind resources and Railways. This image represents three zooms in the output of Wind Resources in model 3 where railways have been displayed on.

9.1.2.6 Land Use:

A distance of 450 m from settlements has been established in order to minimize severe nuisances due to noise and visual impact. Since the company pursues to transmit a good image of the project to citizens, a weight of 15 has been assigned to this criterion.

Analysis:

Times of geoprocessing: Difference in time of processing between the three models follows the general pattern.

Accessible information: As shown in figures 17 and 18, the settlements and their surroundings considerably reduce the final suitable areas, including the three with the most suitable wind resources. The remaining areas obtain 15% of suitability weight for the model 2 and a clear distribution of the weight with the distance for the model 3, since the level of noise generated by the turbines and their visual impact will be lower in further areas.

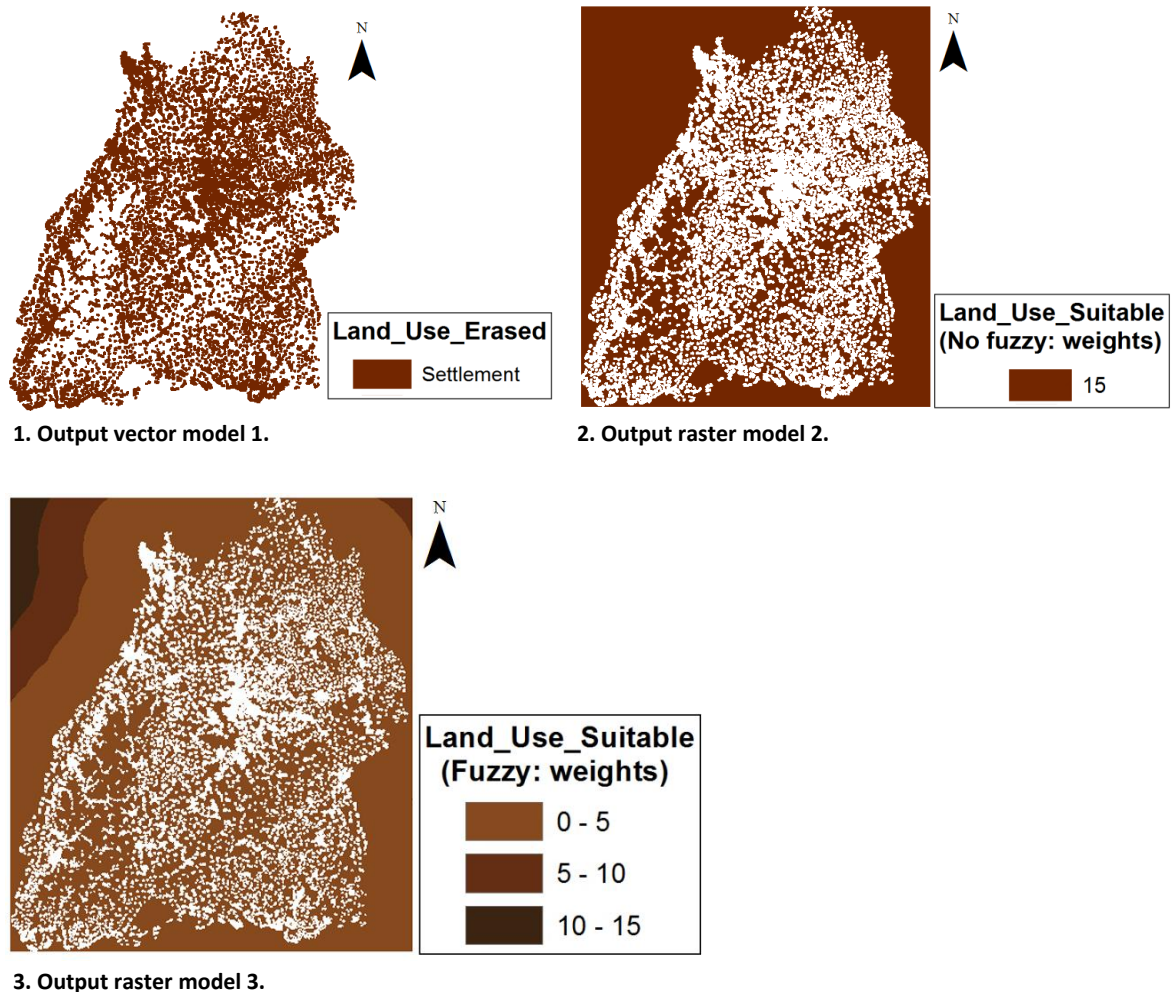


Figure 17: Results from Land Use models. Model 1 generates a vector where settlements and their surroundings (buffered area) are represented. Buffered area is identified in output rasters of models 2 and 3 as NoData, while rest of cells indicates suitability weight.

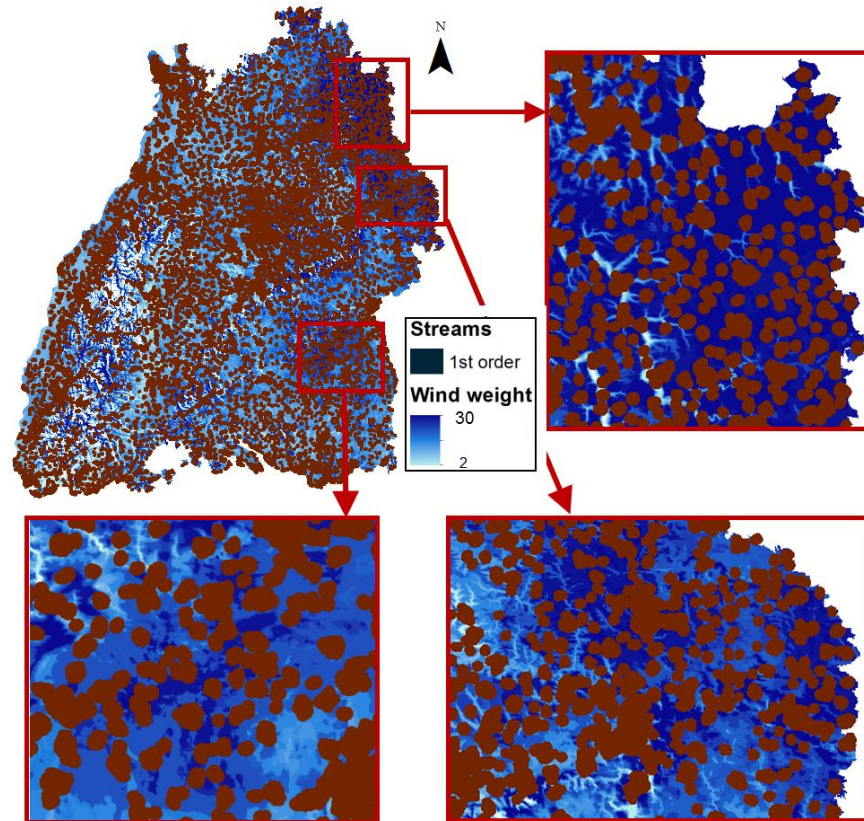


Figure 18: Relation Wind resources and Settlements. This image represents three zooms in the output of Wind Resources in model 3 where settlements have been displayed on.

9.1.2.7 Water bodies:

The company needs to maintain a minimum distance of 150 m from water bodies of first order. Areas outside this distance have been assigned a weight only of 6 because the water resources are not a critical factor in Germany.

Analysis:

Times of geoprocessing: The input vector containing all the water bodies in the region of BW includes lakes and streams. Therefore all of them are processed by the model 1 since a selection by attributes cannot be performed like in the models 2 and 3. Consequently, the differences in times of processing are not as big as with the rest of criteria.

Accessible information: Also the lakes will increase the area erased in the final site selection, being greater in the model 1 than in the models 2 and 3 (see figure 19). Actually, as shown in the figure 20, the streams of first order are not a strong restrictive criterion especially since only few of them cross the areas with the most suitable wind resources. Indeed, they coincide with the hollow areas of the terrain where the wind speeds are slower.

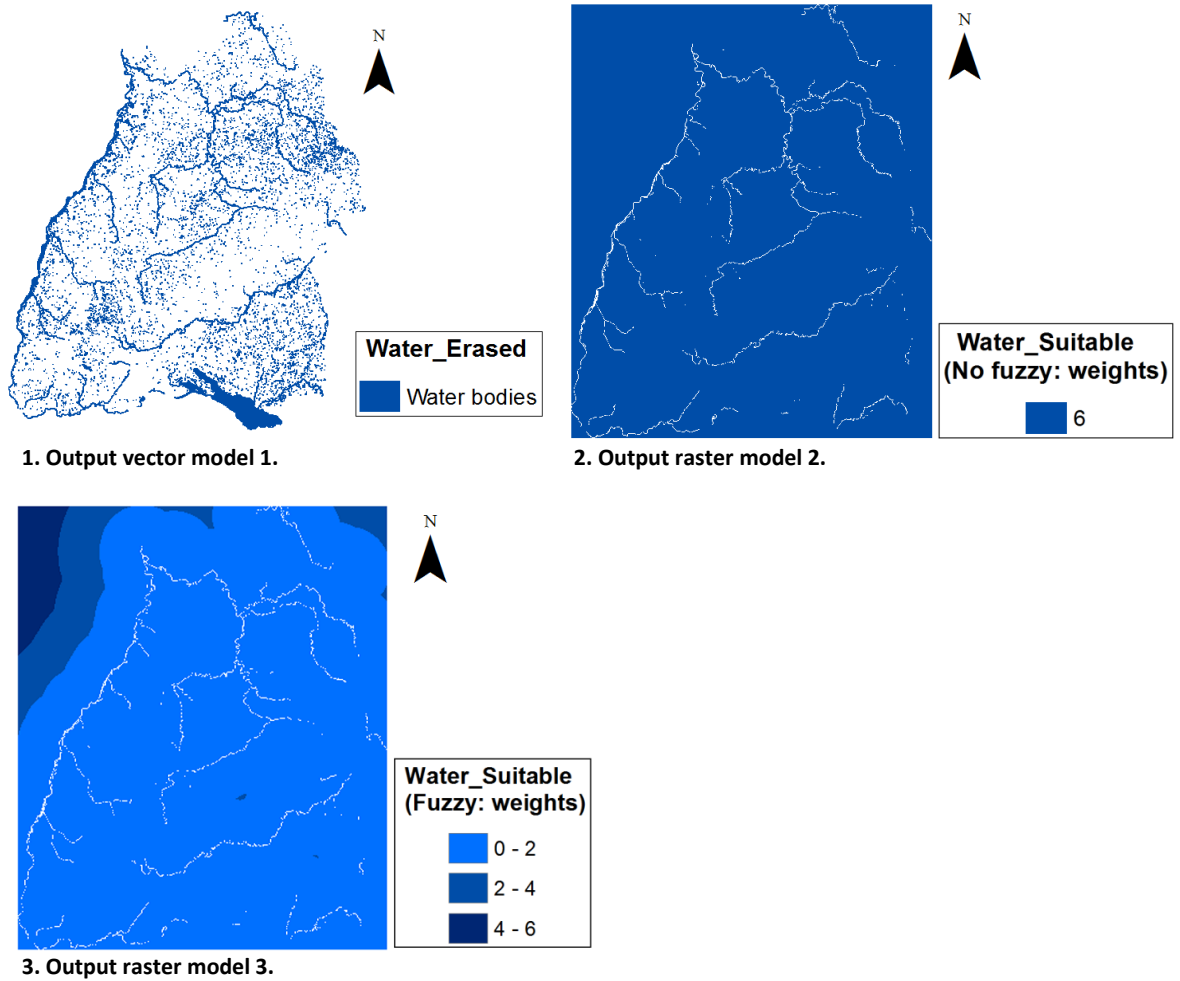


Figure 19: Results from Water models. While model 1 generates a vector where all the water bodies and their surroundings (buffered area) are represented, models 2 and 3 buffer only selected streams which are identified as NoData. Rest of cells indicates suitability weight.

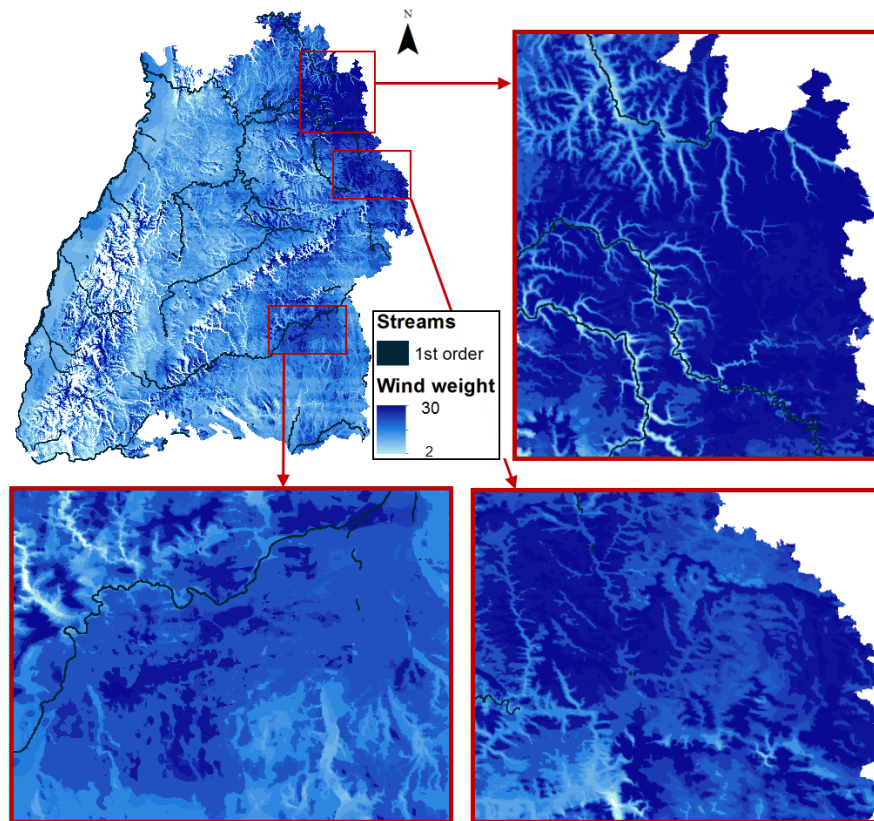


Figure 20: Relation Wind resources and Water bodies. This image represents three zooms in the output of Wind Resources in model 3 where buffered streams of first order have been displayed on.

9.1.2.8 Restricted or protected areas: This criterion has not been processed because no data was provided.

9.1.2.9 Protected areas:

The company has taken into account four protected areas from which a minimum distance has been maintained in order to minimize the impacts derived from wind turbines. The Special Protection Area (SPA) for the protection of wild birds has been assigned a weight of 7 and a distance of 1000 m. The natural reserves have obtained a weight of 7 and 200 m distance. The forest reserves and protective forests have been processed together with a weight of 7 and 200 m distance.

Analysis:

Time of geoprocessing: They follow the general pattern.

Accessible information: As seen in the figures 21 and 22, the areas with the most suitable wind resources are not severely reduced by the natural protected areas, although they will add the minimum suitability weight in the case of model 3.

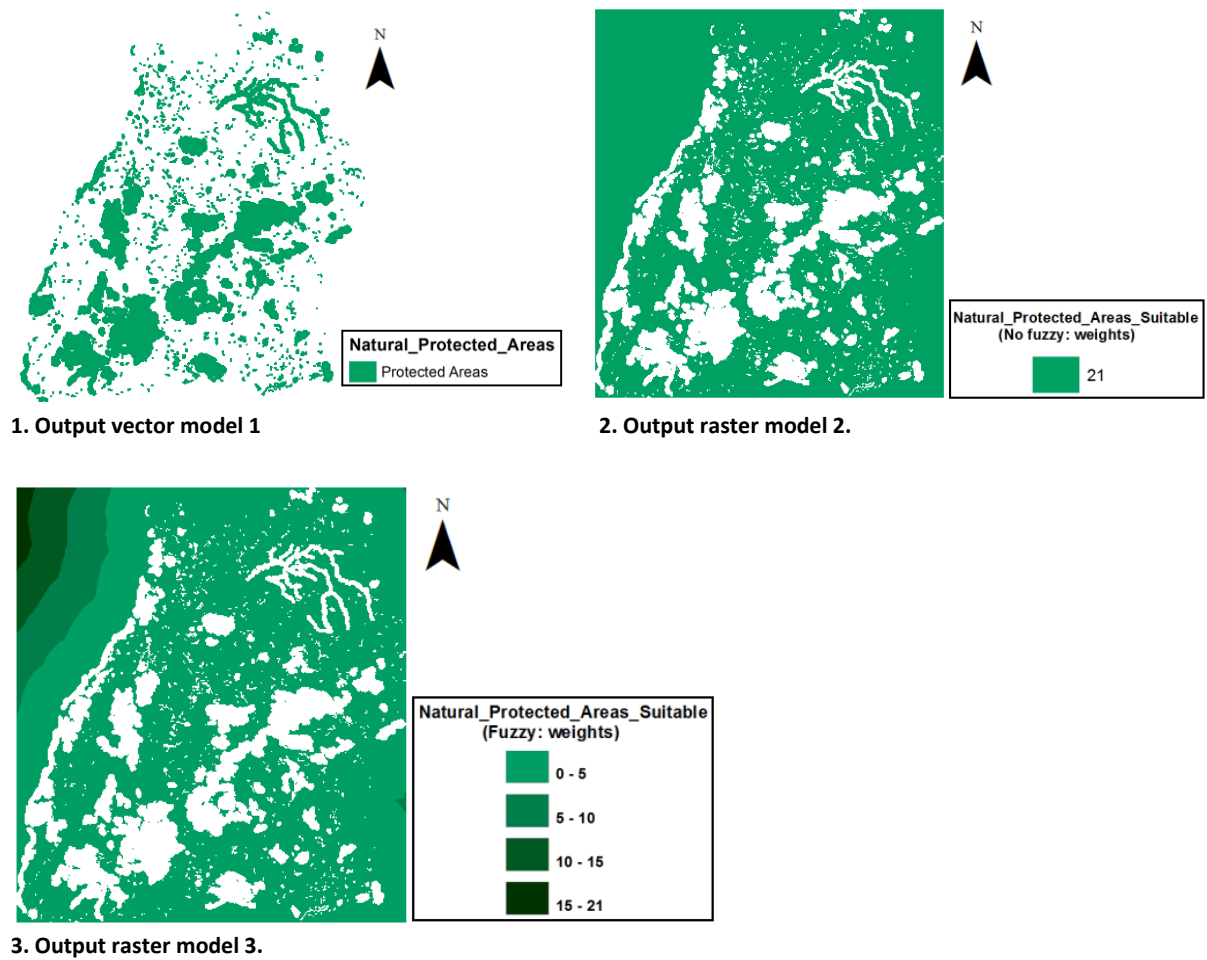


Figure 21: Results from Natural Protected Areas models. *Natural protected areas and their surroundings (buffered area) are represented in green for model 1 (vector output) and in white (NoData) for models 2 and 3 (raster outputs), where rest of cells indicates suitability weight.*

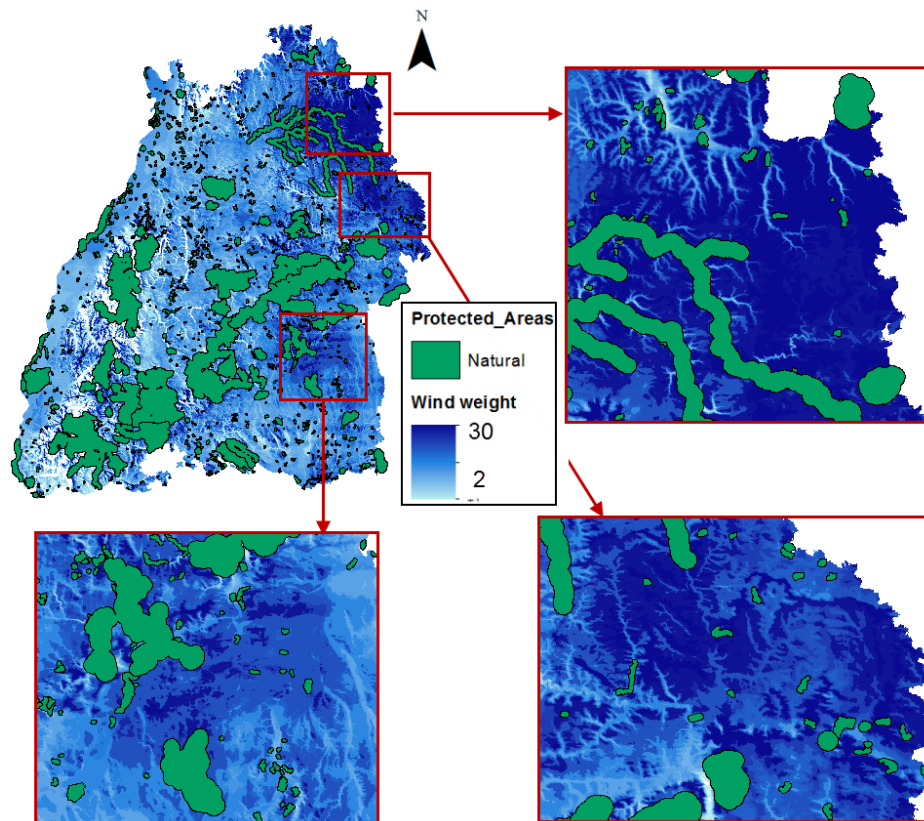


Figure 22: Relation Wind resources and Natural Protected Areas. This image represents three zooms in the output of Wind Resources in model 3 where buffered natural protected areas have been displayed on.

After extracting all the restrictive areas, the required surface for the installation of six turbines must be compared to the available suitable areas in order to see if there is still enough area to install all turbines together or they must be separated in different areas.

Final results: Combination of models

Time of geoprocessing: Model 1, 2 and 3 takes respectively 21'45'', 1^h20'10'' and 2^h1'24'' in order to process all the input data; around 15' more than the addition of all the times needed to process the submodels. Therefore, the tools that combined the outputs of all the submodels take around 15' to calculate the final suitable areas.

Accessible information: As shown in the figures 23 and 24, the three models indicate the same areas with suitable wind resources and where no restricted or protected elements are located. But more information can be extracted with the models 2 and 3. On the one hand, the maximum suitability weight assigned in model 2 is 75%, ergo there is no place in BW where the company can find all the suitable criteria in the same location. On the other hand, the minimum weight assigned is 3 (for slopes and railways); consequently all the areas contain more than one criterion of suitability.

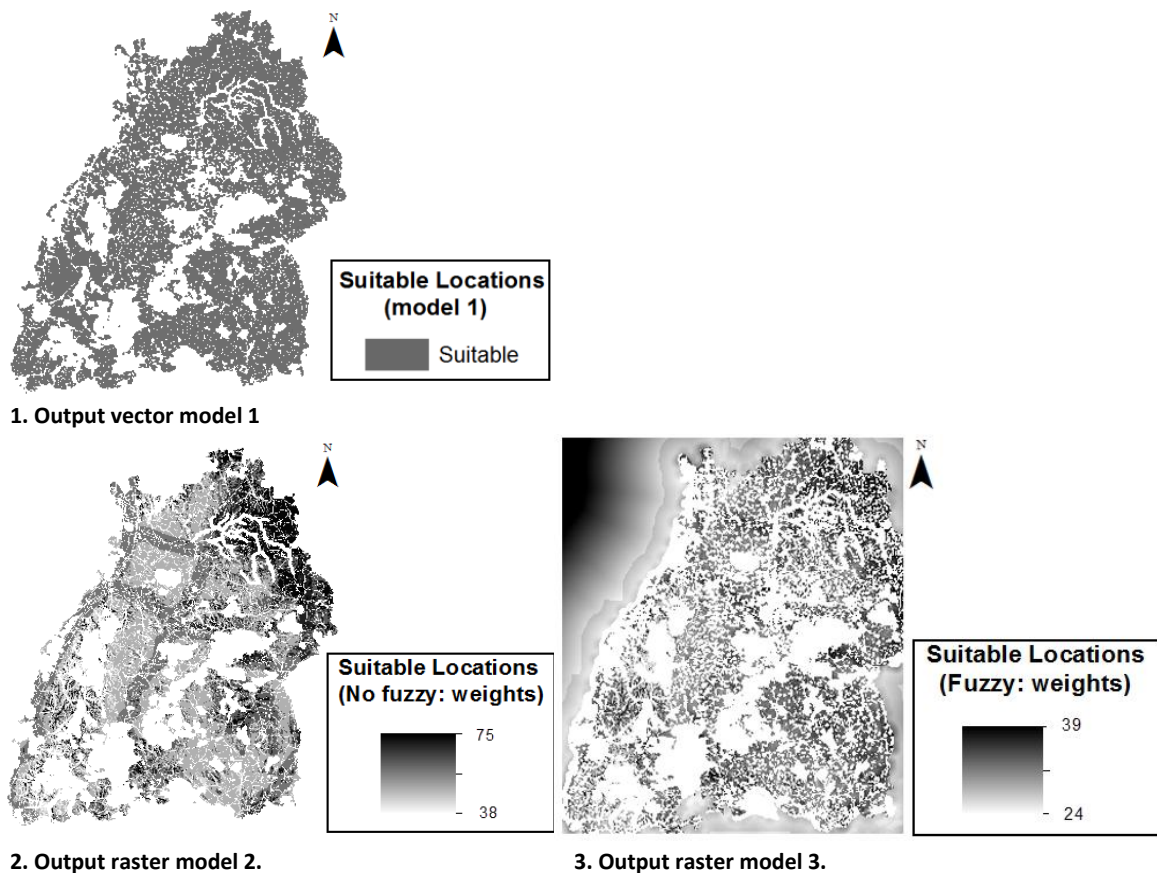


Figure 23: Final outputs of Models. *These images show the final outputs from the geoprocessing of the entire models.*

Moreover, if the percentages of suitability are classified in four categories (see figure 24), an obvious difference in the distribution of weights is found between the model 2, more generous, and model 3. In consequence, the model 2 indicates more locations with the highest percentages.

For instance, the high suitability areas (green color) located in the west side of BW for the model 2 cannot be found in the model 3. Then, if the company takes the decision based on this model and decided to install the wind farm on the west, it will be discarding more profitable areas.

Therefore, the model 3 has been used to develop the desktop application because it contemplates a more accurate representation of the reality since the impacts derived from the installation of wind turbines are always related to the distance.

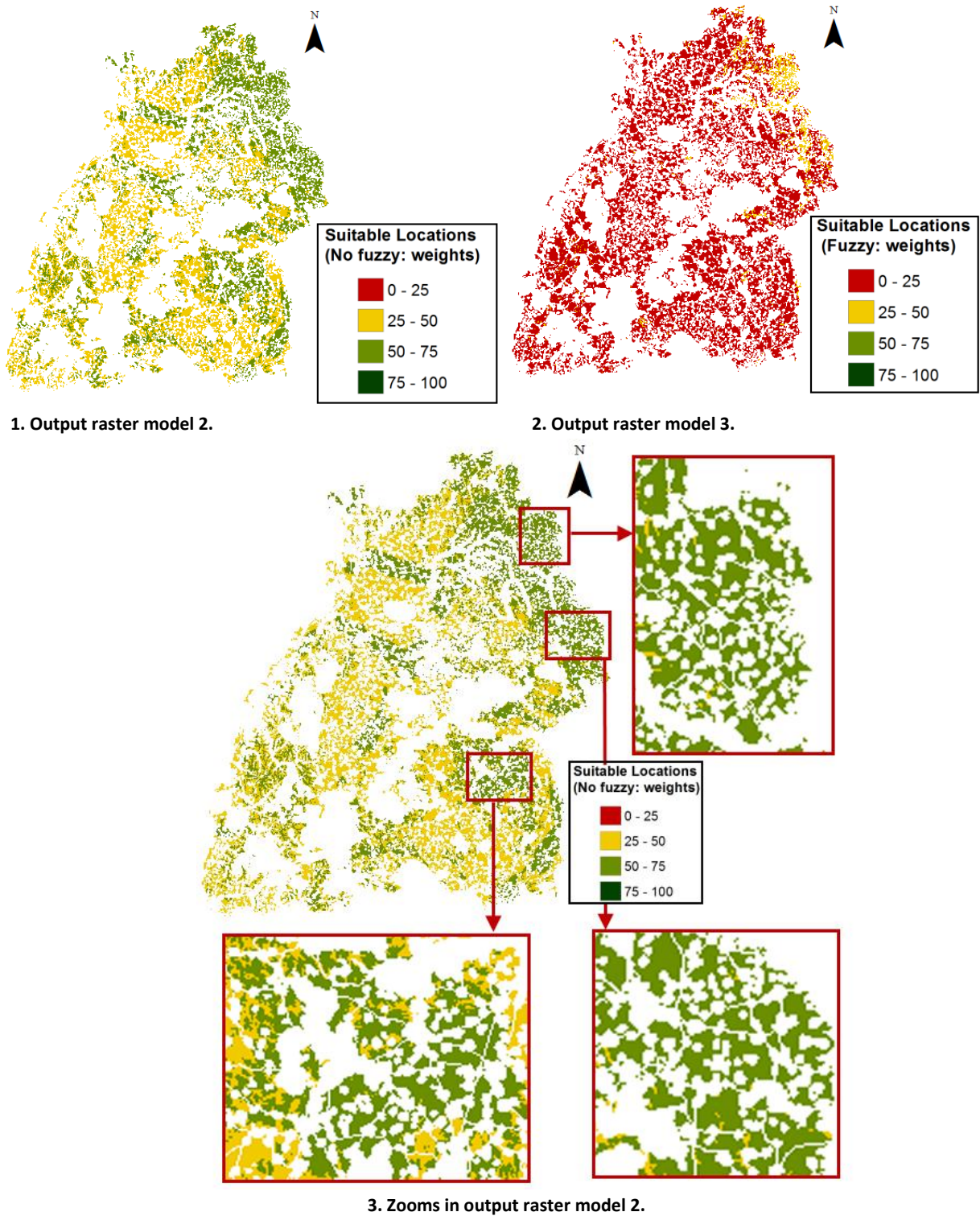


Figure 24: Final outputs of model 2 and 3. These images represent suitable areas for the location of wind farms, classified from low suitability (0 to 25%), low-moderate (25 to 50%), high-moderate (50 to 75%) and high (75 to 100%). Third image includes a zoom in to most suitable areas for model 2.

9.2 Desktop application

The desktop application has been named SISEWIFA 1.0 (Site Selection of Wind Farms) and it has been developed with the third model in order to give a more accurate distribution of weights. The purpose of this development is the extension of the functionalities offered by Modelbuilder, explained in the section 9.2.1 Purpose.

A description of the functionalities, main characteristics and system requirements of SISEWIFA are given as a Software Requirements Specifications document in the section 9.2.2. Besides, a detailed explanation of all the functionalities and sections applied to achieve the purpose of the desktop application is given in the section 9.2.3.

The annex II and III indicates the elements that make the user interface friendlier and the Python code programmed for the desktop application. In addition, a video documentation of the desktop application has been attached with the thesis.

9.2.1 Purpose: Advantages over ModelBuilder

On the one hand, while Modelbuilder demands to complete all the inputs that have been included inside the model, they become optional with the desktop application. SISEWIFA's interface includes a check button per criterion: if the button is selected, the criterion will be processed with the input parameters assigned by the users through the interface. Then, the output generated will be stored in a system of geodatabases which is managed in order to make all the inputs optional (an explanatory example is given below).

For example, the wind resources section allows four possible individual selections from which a user only plans to process the first and the second one. The two generated raster datasets are directly stored inside the database "Suitable_WindResources.gdb". Afterwards, an arcpy function identifies all the rasters contained inside that database and stores their names in a Python list. Then, a loop reads and combines each raster inside the list, making irrelevant the number of stored rasters, ergo inputs become optional.

Thereupon, two new situations might appear. First, the user realizes that the assigned parameters for the second selection are very restrictive, generating a very small surface of suitable resources. For this case, the interface includes a reset button for each selection which let the user to perform again the second selection with new parameters. Then, the programmed code overwrites the outputs previously generated so that the modifications are recorded. Hence, when all selected wind resources are combined, they will include the results from the old first selection and the new second selection.

Another situation could appear if the user has already processed the second selection and decides to continue the site selection only with the first one. In this case, the output of first selection must be deleted in order not to be processed in the final combination. This is handled with a combination of if/else statements and an arcpy function which delete rasters.

As shown in the example of table 8, first the “Suitable_WindResources.gdb” is set as workspace for which an arcpy function identifies all the raster datasets contained inside and inserts their names into an empty Python list. Once the code detects that the wind at first selection’s check button is unselected, it automatically assigns this section a weight of 0. Afterwards, Python reads inside the list searching for the output of this criterion. If it is found, another arcpy function will delete it. If not, a message will indicate that it has not been processed yet. This condition statement is essential for handling errors, since if no raster is found and the arcpy function is executed an error is generated and the geoprocessing stops.

Table 8: Optional inputs with Python I. This table includes a piece of Python code from the developed desktop application, showing how inputs become optional. On the left the codes are represented as they appear in the Python’s editor IDLE and on the right the comments explaining what the code does. Afterwards the code continues with the processing corresponding to each criterion.

Code	Comment
env.workspace = dirWindR	## Set the database as workspace
Rasters = arcpy.ListRasters ()	## List all rasters inside the database
ckbWR1 = varCkbWR1.get()	## Detect if check button is selected
if ckbWR1 == "no":	## If it is not selected
time1 = float (0)	## It adds no weight
if u'Wind1_Suitable' in Rasters:	## If it has been previously processed
print "Wind 1 will be deleted"	## Indicate it will be deleted
arcpy.Delete_management(outSuiCalWR1)	## Delete it
else:	## If it has not been previously processed
print "Wind 1 does not exists"	## Indicate it does not exist
if ckbWR1 == "yes":	## If it is selected
time1 = float (entWR14.get())	## Get user's weight

The other purpose of the desktop application is the creation of a more user friendly interface to the model. After a model has been created and the model parameters are set up, the model can be run in ArcGIS Desktop like other GIS tool, opening a dialog window which requests the users to introduce the input values. ModelBuilder offers the possibility to organize and rename the model parameters in order to make them more intuitive for the users. For example, the figure

Figure 25 shows a dialog that opens when running the Land use submodel, which includes 24 model parameters distributed inside a scrolled window. Then if the entire model were run, the number of model parameters would reach 108 input variables listed inside this dialog box.

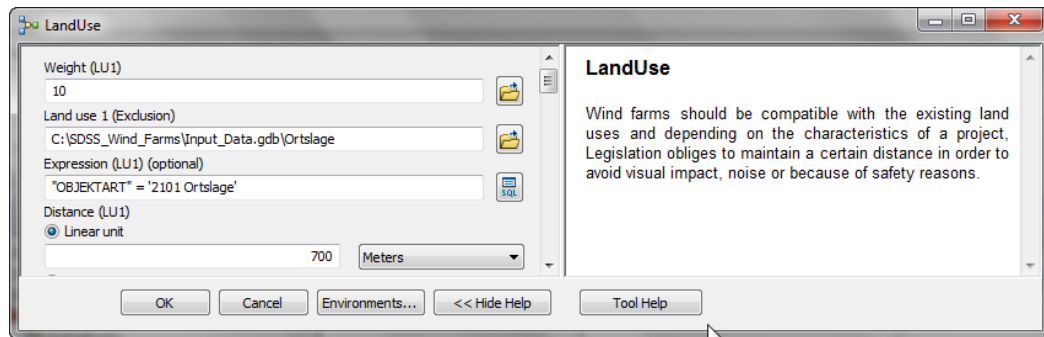


Figure 25: Dialog box for a Land Use in ModelBuilder. This image represents the dialog box which appears when running the submodel of Land Use for models 2 or 3 from ModelBuilder.

In order to create a friendlier interface, a conceptual design of the SDSS has been carried out in order to organize these criteria in a more intuitive structure, as well as to include additional functionality to cover the potential users' needs (explained in the next sections). As a result, the submodels have been classified by categories (Technical requirements, Abiotic impacts and Biotic impacts) separated in different views within the interface (see figure 26). Afterwards, the SDSS has been implemented by building the GUI and connecting it to the programmed code which contains the GIS functionality.

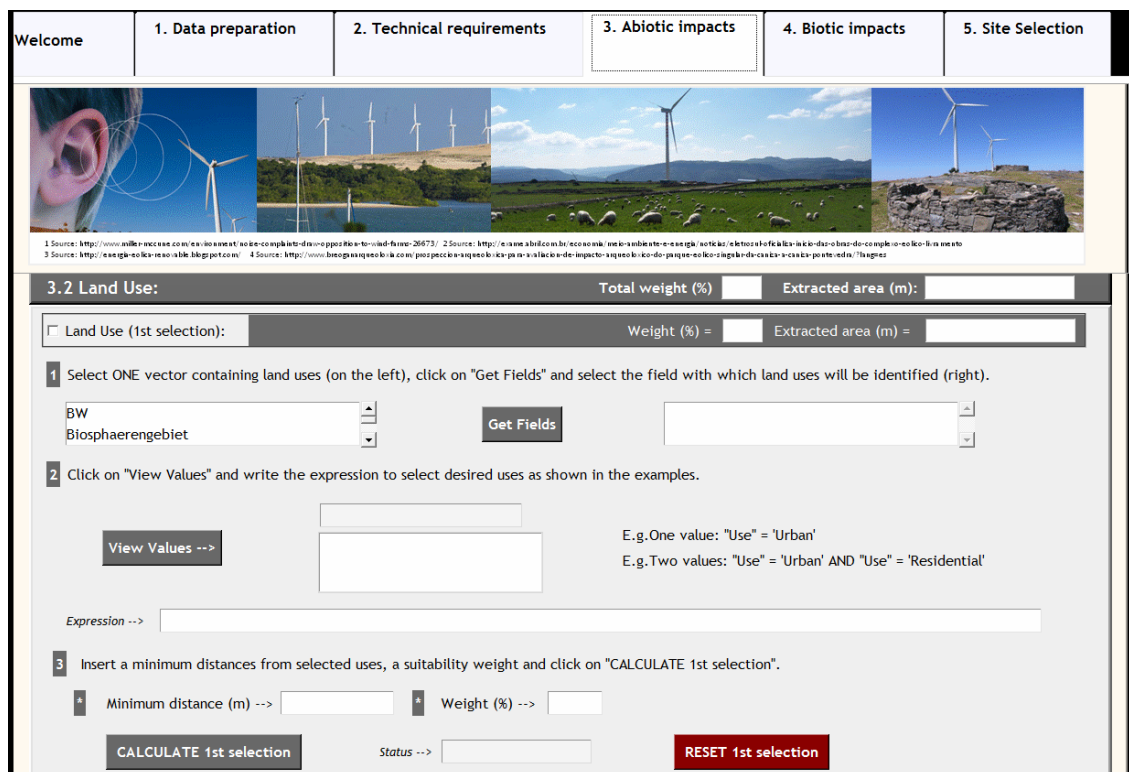


Figure 26: Land Use in the desktop application. This image represents a screenshot of land use in the tab of abiotic impacts of SISEWIFA. More information is given in next sections.

9.2.2 Software Requirements Specification (SRS)

These specifications follow the general guidelines of the Software Requirements Specification report for software documentation.

A. Purpose: The main purpose of SISEWIFA 1.0 is the performance of a spatial analysis on input data in order to exclude inadequate areas for the installation of wind turbines and assign a weight of suitability to those areas with profitable wind resources according to the optional input criteria.

It has been designed to generate and evaluate project's alternatives of location in order to support the decision making process during the Environmental Impact Assessment of wind energy projects.

B. Functionality: SISEWIFA shall:

- Make optional the geoprocessing of all the inputs of the model.
- Identify the location of the application inside the computer, store it as a global variable and combine it with the corresponding relative paths necessary to indicate geoprocessing functions where to find the inputs and store the outputs in an adequate system of databases.
- Get input parameters inserted in the interface and assign them to the corresponding geoprocessing tools in order to perform the required spatial analysis.
- Insert in the interface the assigned weights and change of areas after the execution of restrictions, making this information accessible to users.
- Automatically open a map document in ArcMap 10 showing the final suitable locations with a predefined symbology.
- Export the map to a pdf file.
- Open help menus when selected and pop up messages when the cursor is placed on highlighted elements (see Annex III).
- Indicate the beginning and end of each geoprocessing in a status bar.

C. Attributes: SISEWIFA 1.0 can be stored anywhere in the computer. Users indicate its location creating a global variable that is combined with relative paths to a system of geodatabases required to make the inputs optional. Consequently, ArcGIS functions understand where to find the inputs and locate the outputs, obtaining the geoprocessing tools' parameters from entries created in the interface.

On the other hand, it is not meant to be a standalone application since ArcGIS Desktop 10 must be still installed in order to access the arcpy module which supports the geoprocessing functionality, as well as Python 2.6, tkinter and tix which come included inside its installation package.

Besides, SISEWIFA is "Transparent To The User" (TTTU), not demanding knowledge in the involved technologies. Therefore, the insertion of the right parameters would only depend on the knowledge on wind energy and environmental sciences.

D. System requirements: The same as ArcGIS Desktop 10 (see Table 9).

Table 9: SISEWIFA 1.0 system requirements. They are the same as for ArcGIS Desktop 10 obtained from ArcGIS Resource Center (<http://resources.arcgis.com/content/arcgisdesktop/10.0/arcgis-desktop-system-requirements>).

Type	Requirement	
Operating system:	Windows	XP,2003, Vista, 7 and 2008
Hardware:	CPU speed	2,2 GHz
	Processor	Intel Core Duo
	RAM	2GB
	Disk Space	2.4 GB
	Display properties	24 bit color depth
	Screen resolution	1024 X 768
	Video/Graphics adapter	64 MB RAM. NVIDIA, ATI and INTEL chipsets. 24 bit capable accelerator OpeGL version 2.0 or higher. Shader Model version 3.0 or higher.
Software:	.NET Framework	3.5 SP1
	Microsoft Internet Explorer	7.0 or 8.0
	Python	2.6
	ArcGIS Desktop	10

D. Installation: Users obtains a folder called SDSS_Wind_Farms which can be stored anywhere in the computer. The package includes an executable Python script containing the application, a folder with images imported by the script, two folders to stored layers and map documents generated by the application, a system of geodatabases to manage the geoprocessed data, a toolbox containing the models which can be also processed in AcrGIS Desktop 10, a text file with installation instructions which easily explains how to start the application (see figure 27), a map document which will be opened representing the suitable locations and finally a layer from which the simbology will be imported to the generated maps. See figure 28.

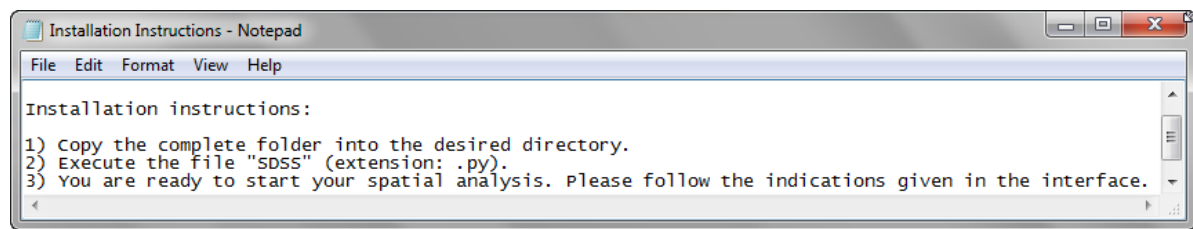


Figure 27: Installation instructions. Text file of the SDSS containing instructions to start the desktop application.

Name	Type
Images	Folder
OutputLayers	Folder
OutputMxd	Folder
Input_Data.gdb	File Geodatabase
Scratch.gdb	File Geodatabase
Suitable_Areas.gdb	File Geodatabase
Suitable_LandUses.gdb	File Geodatabase
Suitable_NaturalPA.gdb	File Geodatabase
Suitable_ProtectedAreas.gdb	File Geodatabase
Suitable_Railways.gdb	File Geodatabase
Suitable_Roads.gdb	File Geodatabase
Suitable_Water.gdb	File Geodatabase
Suitable_WindResources.gdb	File Geodatabase
Wind_Farm_Locations.gdb	File Geodatabase
SDSS_ModelBuilder.tbx	Toolbox
Installation Instructions.txt	Text File
SDSS.mxd	Map Document
Symbology.lyr	Layer

Figure 28: SDSS folder. Visualization of the SDSS folder in arcCatalog.

E. External interface: This interface contains two principal components. The first one is a menu with information about the SDSS, wind energy and a more detailed explanation about how to use the application. The second one is a notebook element from the tix module with a thumb index indicating the right sequence to follow in order to complete the spatial analysis and generate a map with the most suitable locations. The interface index is as follows:

- ❖ Welcome tab.
- ❖ 1.Data Preparation.
 - 1.1 Instructions.
 - 1.2 Require data.
 - 1.3 Import all your data.
 - 1.4 Raster vector transformations.
 - 1.5 Limit your area of study.
 - 1.6 Resampling
- ❖ 2. Technical requirements.
 - 2.1 Wind resources.
 - 2.2 Terrain slopes.
 - 2.3 Roads.
 - 2.4 Power lines.
- ❖ 3. Abiotic impacts.
 - 3.1 Railways.
 - 3.2 Land use.
 - 3.3 Water bodies.
 - 3.4 Restricted or protected areas.
- ❖ 4. Biotic impacts.
 - 4.1 Natural protected areas.
- ❖ 5. Site selection.

9.2.3 Interface explanation

❖ **Welcome tab:** Additional documentation can be found in the figure 29 and the video documentation “1.WelcomeTab.avi”.

SISEWIFA can be stored anywhere in the computer generating the difficulty to indicate the software where to find the inputs and images or locate the outputs. For this purpose, the users indicate here the location of the folder “SDSS_Wind_Farms” which will be combined with other paths during the application, in order to manage the data inside the system of databases created to make all the inputs optional.

Detailed description:

The path is stored as a global variable and joined with other relative paths in order to provide ArcGIS functions with the demanded parameters. For this purpose, the module operating system is imported into the script. First a join must be performed with “os.path.join”. Then it must be transformed to a canonical path in order to eliminate any symbolic links (<http://docs.python.org/library/os.path.html>) with “os.path.realpath”.

Instead of writing the path directly, the button “File Selection” calls a function which pops up a new window where the users can navigate and select the folder “SDSS_Wind_Farms”. Once the right path is inserted, an image appears and the users are indicated to proceed (see figure 29). If a wrong path is inserted, the code is not able to find the image since the real path does not reach the image folder. After the path is selected, an arpy function identifies all the vectors and rasters inside the database and stores them in two different Python lists, which will be inserted in the corresponding listboxes from which the users need to select the inputs.

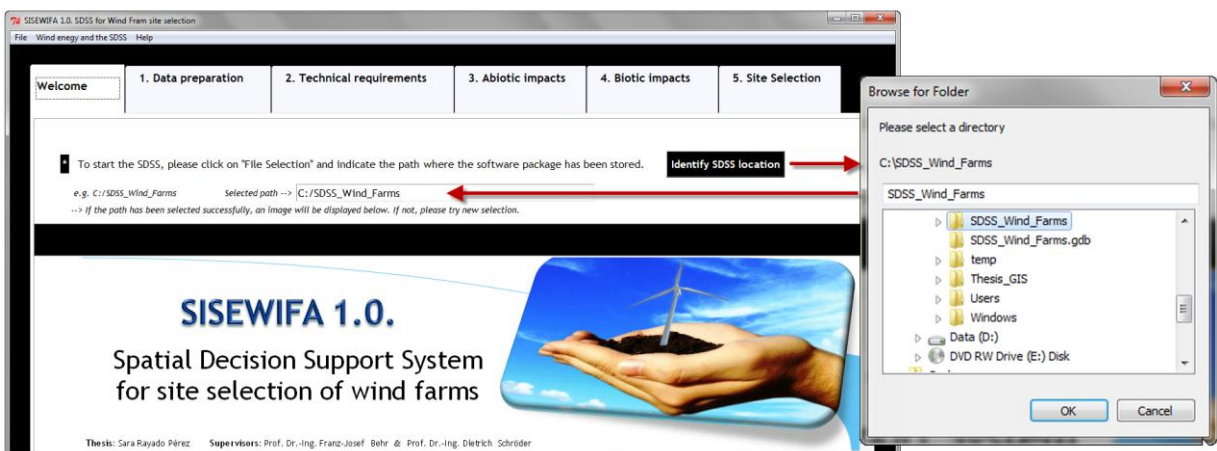


Figure 29: Welcome tab. This image shows the first tab of the desktop application. The file selection button calls a function which opens the window (on the right) where users can easily indicate the path to the application’s folder. If the correct path is inserted, the image of SISEWIFA appears as confirmation.

❖ **1. Data preparation tab:** Additional documentation can be found in the figures (from the 30 to 36) and the video documentation “2.DataPreparationTab.avi”.

1.1 Instructions (figure 30): It contains a summary of instructions about how to use the application, including where to find more detailed information (menus and pop up messages). Some examples are given in Annex I.

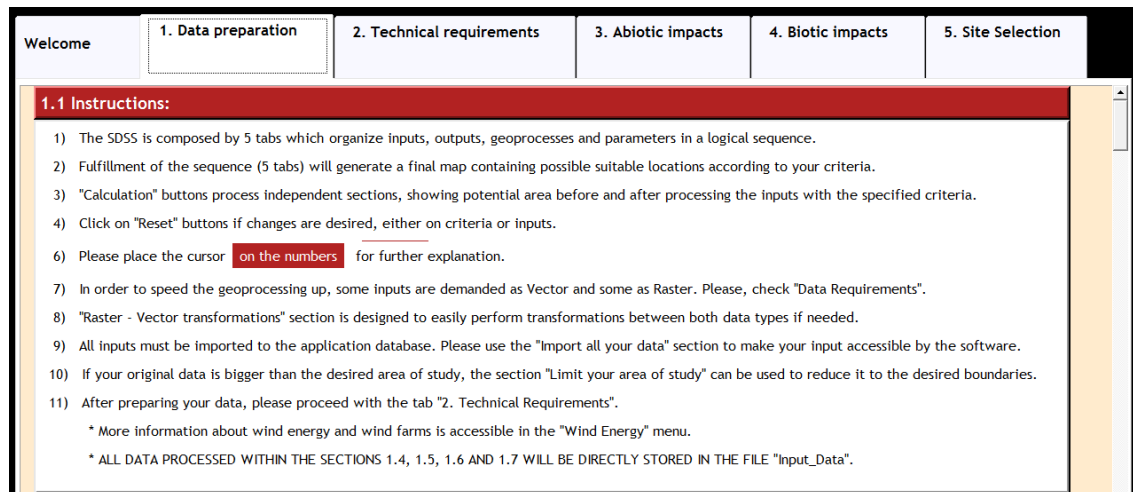


Figure 30: Data preparation tab: Instructions.

1.2 Required data (figure 31): A list of required data specifies the demanded input format for each criterion. Some geoprocesses have been designed to demand input data as vector and some as raster taking into consideration which one is normally faster according to the nature of the represented entities.

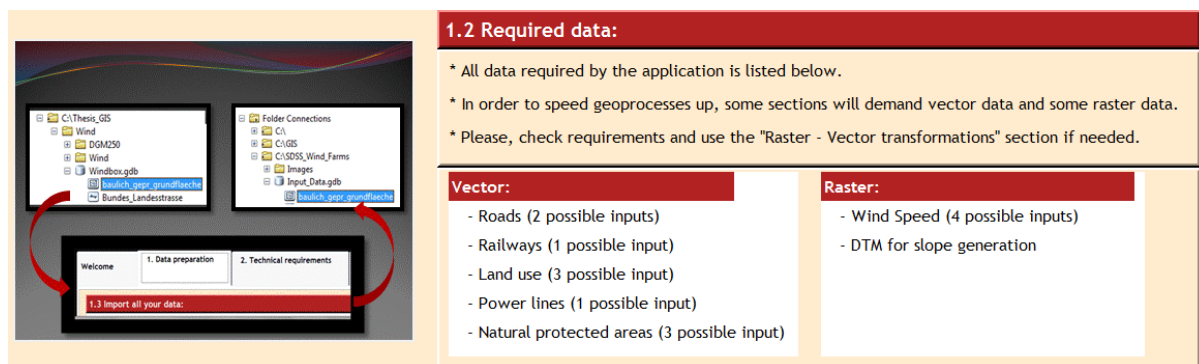


Figure 31: Data preparation tab: Required data.

1.3 Import all your data (figure 32): The users are asked to import all their data into the input database of the application. The purpose is to improve data organization and facilitates the user’s selections during the application, since all the data contained in this database will be accessible each time a user needs to select an input.

Detailed description:

Users can import their data to the "Input_Data.gdb", either directly in ArcCatalog or using the frame "Import all your data" (slower but no need to open ArcGIS software). In the second manner, the function invoked by the "Select source" button opens a window where users indicate the target directory with the source data. This lists automatically all the vectors and rasters inside their corresponding boxes. Then, the user selects one entry from the listbox, inserts a desired output name and clicks on "Import" invoking its storage directly inside this "Input_Data.gdb".

Actually, each criterion's section includes a listbox where the possible inputs are listed. This is achieved thanks to an arcpy function that identifies the data formats inside the "Input_Data.gdb" storing the vectors in one Python list and the rasters in another. Hence, every time the users must select a vector, only the vectors' list is inserted in the corresponding listboxes (the same for raster). This avoids errors generated if assigning a wrong input format to a geoprocessing tool.

In addition, several messages appear to give additional information to the users. Two messages of "Processing" and "Complete" appear inside the status box when processing starts and finishes. Besides, if no data is found in the target directory, a message will warn the users. This message concept will be used during the whole application.

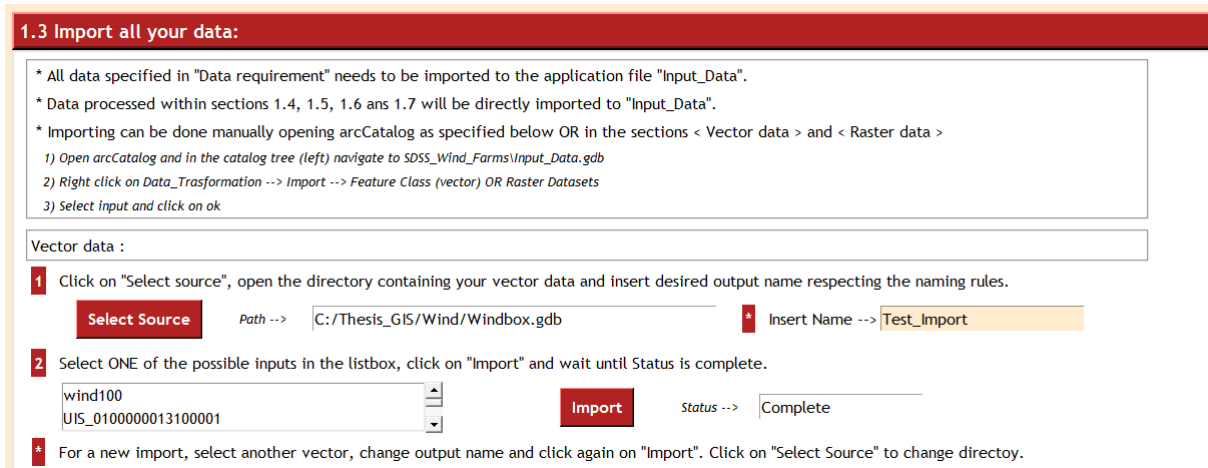


Figure 32: Data preparation tab: Required data. Raster's section has the same view as vector's section.

1.4 Raster – Vector transformations (figure 33): This frame might be needed if the original data are in a different format from the one specified in data requirements. Otherwise, the geoprocessing functions will not run since they are designed to work with a concrete format, ergo a transformation from raster to vector or vice versa is very important.

Detailed description:

In the case of vectorization (raster to vector), users select a raster from the listbox and transform it to the adequate geometry. For instance, a raster containing land uses must be transformed to polygons while in the case of roads, they are normally transformed to polylines.

Rasterization (vector to raster) follows a similar methodology but requires two new parameters: The value which will be used to create the raster and the cell size of the output raster. In the first case, once the user select a vector and click on “Get Fields”, all the fields contained inside the table of attributes of that vector are listed. They must select the one which will give its final values to the output raster. In order to be secure of the right election, users are able to check its values with “View Values”. This button invokes a function which creates a search cursor that reads inside the table extracting all the possible values of the selected field.

In the second case, the users must determine the size cell, which corresponds to the spatial resolution. Additional information advises users to take into consideration that while a very big cell size reduce the precision of representation of a feature, a very small cell increase cost of data storage and speed of processing (Prithvish & Sengupta, 2007).

1.4 Raster - Vector transformations:

Vectorization (Raster to Vector):

- Click on "Select source", open the directory containing your raster data and insert desired output name respecting the naming rules.
Select Source Path --> C:/SDSS_Wind_Farms/Input_Data.gdb * Insert Name --> Test_Vectorization
- Select ONE of the raster, transform it to the desired geometry and wait until Status is complete.
Stuttgart_Wind1
Stuttgart_Wind2 POLYGON POLYLINE POINT Status --> Complete
- * For a new import, select another raster, change output name and click again on corresponding geometry. Click on "Select Source" to change directory.

Rasterization (Vector to Raster):

- Please click on "Select source" and navigate to the directory containing your vector data.
Select Source Path --> C:/SDSS_Wind_Farms/Input_Data.gdb
- Select ONE of the vectors listed (on the left), click on "Get fields" and select the field (on the right) which will give the values to the raster.
Stuttgart_BundesLandst
Stuttgart_Bundesautobahn Get Fields FKT FSZ
- Click on "View Values" to visualize the values of the selected field.
View Values 1 2
- Insert desired output name and cell size. * Name --> Test_Rasterization * Cell size --> 50
- Transform your geometry to raster and wait until Status is complete. For new rasterization repeat the process. Click on "Select Source" to change directory.
from POLYGON to Raster from POLYLINE to Raster from POINT to Raster Status --> Complete

Figure 33: Data preparation tab: Raster-Vector transformations.

1.5 Limit your area of study (figure 34): Own data might contain information about an area bigger than the one of Study, what will slow the geoprocessing down. In such cases, SISEWIFA allows users to generate a boundary which encloses the area of study in order to extract it from all their input data and avoid unnecessary processing.

Detailed description:

First, users select the vector data from which the boundaries will be generated and create a SQL expression to extract only the desired regions. For example, the users select a map of states, click on “Get Fields” and select “State_Name”. In order to build a SQL expression, they are provided with a combobox where all the possible values for a selected field can be visualized, copy and paste where the expression must be inserted.

This minimizes possible syntax errors. Once the boundaries have been created, the user's rasters and vectors can be processed, extracting only the data inside the boundaries and storing them directly inside the "Input_Data.gdb".

1.5 Limit your area of Study:

Establish the boundaries for the area of study:

- 1 Click on "Select source" and navigate to the directory containing the vector data from which the boundaries will be generated.

Select source Path --> C:/SDSS_Wind_Farms/Input_Data.gdb
- 2 Select ONE of the vectors listed, click on "Get Fields" and select the field containing the criteria to select the boundaries.

Ortslage Shconwald	Get Fields	GN FFC
-----------------------	------------	-----------
- 3 Click on "View Values" to Visualize all possible values for the selected Field.

View Values -->

Stuttgart
Stutensee
Stuttgart
Stöttlen
- 4 Write in the given box the SQL expression to generate the boundaries as shown in the examples.

"GN" = 'Stuttgart'

--> 1 Value: "Name" = 'Stuttgart'

--> 2 Values: "Name" = 'Stuttgart' AND "Name" = 'Sulz am Neckar'

--> 3 Values: "Name" = 'Stuttgart' AND "Name" = 'Sulz am Neckar' AND "Name" = 'Überlingen'
- 5 Enter the desired output name for the boundary -->

Test_Boundary
- 6 Click on "Generate Boundary" and wait until status is complete.

Generate Boundary Status -->

Complete

Reset Boundary Section

Notice: The boundary will be directly stored inside "Input Data".

Extract (clip) the area limited by the boundaries for your VECTOR data:

- 1 Click on "Select source" and navigate to the directory containing the vector from which extract the boundary.

Select source Path --> C:/SDSS_Wind_Farms/Input_Data.gdb
- 2 Select ONE vector, insert output name, click on "Extract Boundary and wait until Status is complete".

Kreisstrasse Eisenbahnstrecke	* Name -->	<div style="border: 1px solid #FFD700; padding: 2px; background-color: #FFD700;">Test_BoundaryV</div>	Extract Boundary	Status --> <div style="border: 1px solid #FFD700; padding: 2px; background-color: #FFD700;">Complete</div>
----------------------------------	------------	---	--	--
- * For new extraction select another vector, change output name and click again on "Extract Boundary". Click on "Select Source" to change directory.

Extract the area limited by the boundaries for your RASTER data:

- 1 Click on "Select source" and navigate to the directory containing the raster from which extract the boundary.

Select source Path --> C:/SDSS_Wind_Farms/Input_Data.gdb
- 2 Select ONE raster, insert output name, click on "Extract Boundary and wait until Status is complete".

Stuttgart_DTM WindAtlas_100	* Name -->	<div style="border: 1px solid #FFD700; padding: 2px; background-color: #FFD700;">Test_BoundaryR</div>	Extract Boundary	Status --> <div style="border: 1px solid #FFD700; padding: 2px; background-color: #FFD700;">Complete</div>
--------------------------------	------------	---	--	--
- * For new extraction select another raster, change output name and click again on "Extract Boundary". Click on "Select Source" to change directory.

Figure 34: Data preparation tab: Limit your area of study.

1.6 Resampling your rasters (figure 35): While rasters might be stored with different cell resolution, they must have the same cell size when geoprocessing is performed. There are four resampling techniques: nearest neighbor (NN), majority, bilinear and cubic interpolation. This section allows the users to perform any of them and to obtain an explanation of these techniques inside the help menu.

Finally, a frame reminds users to refresh the database after preparing all their data. This is very important since the Python lists created in the welcome tab must be updated in order to include the new inputs generated in this tab (See figure 36).

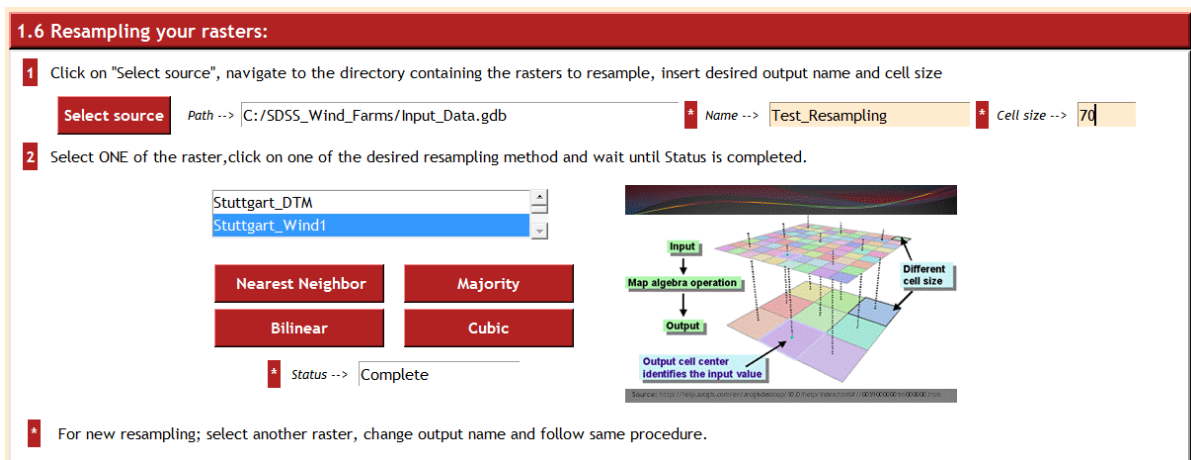


Figure 35: Data preparation tab: Resampling your rasters.

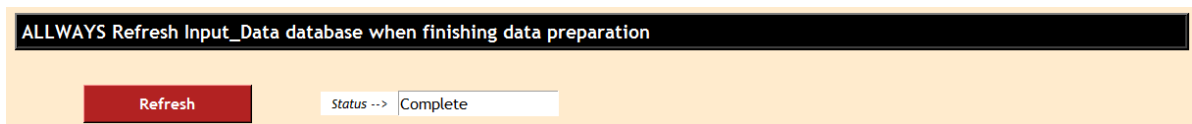


Figure 36: Data preparation tab: Refresh "Input_Data.gdb".

❖ **2. Technical requirements tab:** In this tab wind resources, slopes, roads and power lines are processed. Further documentation can be found in figures (from the 37 to the 41) and the video documentation “3.TRTabl.avi” and “4.TRTabl.avi”.

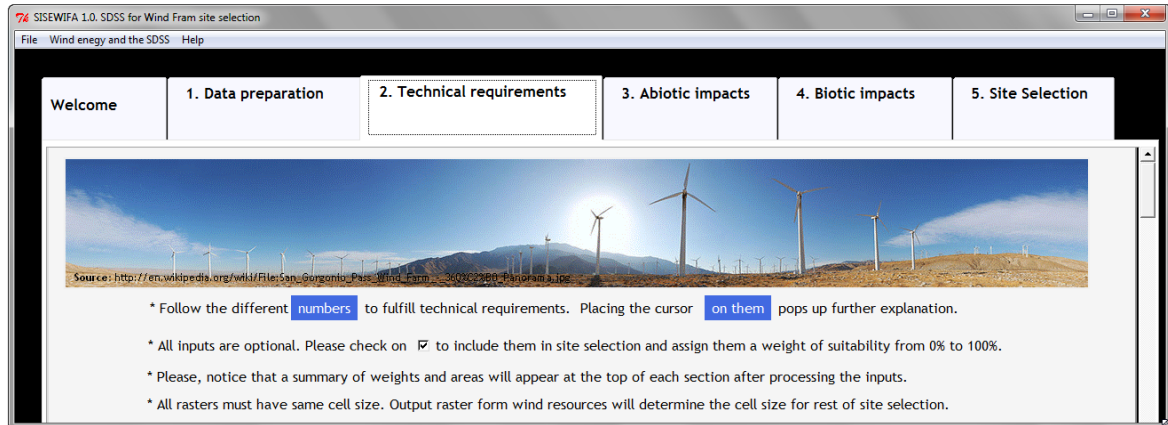


Figure 37: Technical requirements tab.

2.1 Wind resources (figure 38): This section allows users to perform four different selections, either with different inputs or with ranges of speed.

Detailed description:

Operation: First the users select a raster in the first listbox, where all the raster stored in the “Input_Data.gdb” have been listed by functions invoked in the previous tabs. Afterwards, an arcpy function lists all the fields of the VAT of the selected raster, which are automatically inserted in the second listbox. In this manner, users are allowed to select the field which contains the wind speeds.

The “View Values” button invokes a function which creates a search cursor to read and extract the speeds values, storing them inside a Python list which is directly inserted into the third and fourth listboxes. From these boxes, a range of speed is selected and the SQL expression required to select wind speeds is automatically generated and inserted in a text box, so that users can check the selection at any time. A blue text box indicates users that they must insert an input value, in this case the weight that will be inserted into the geoprocessing workflow.

Provided information: There are two information bars. One at the top of each criterion that indicates the total weight assigned to that criterion and the surface carrying this suitability weight. Besides, there is another information bar for each selection indicating the individual weight as well as the input and output areas so that the users can realize the effect of their restrictions. Thus, a modification of the parameters can be performed if needed.

Furthermore, the Status bar indicates several messages during the processing. If users have forgotten to select the check button, a message of “unchecked” appears. This is very important since only checked criteria will be processed in the final site selection. Then a “processing” text indicates that the code has

started to process the input data. Finally a "complete" message indicates that the geoprocessing has been successful.

Besides, all the highlighted numbers and asterisks contain pop up messages with relevant information which could clarify potential users' doubts.

Figure 38: Technical requirements tab: Wind resources.

Since the same principles have been applied to the rest of the interface, only the main differences will be comment for the next criteria and only one of the possible selections will be represented in the figures. A complete visualization of the interface as well as additional information can be found in the video documentation attached with the thesis and in the code located in the Annex III.

2.2 Terrain slope (figure 39): This section generates a raster of slopes from a DTM and selects those which are equal or smaller than the degree inserted by the user. Suitable slopes obtain the inserted weight.

Figure 39: Technical requirements tab: Terrain slope.

2.3 Roads (figure 40): Two possible selections are offered but in this case the users are asked to generate the SQL expression for selecting the roads due to the difficulty in predicting the criteria that they will use to select them. For example, they might want to select roads based on the pavement's characteristics, width, type or length.

Detailed description:

In order to facilitate the generation of the expression, a combobox lists all the possible values for a selected field. When a value is selected, it is automatically inserted on the top of the box, where it can be copied and pasted directly into the "Expression" box, minimizing possible syntax errors.

Figure 40: Technical requirements tab: Roads.

2.4 Power lines (figure 41): The interface allows increasing the suitability for those areas which are close enough to a selection of power lines.

Detailed description:

In this case the data inserted in the information bar at the top of the section would have been the same as for the individual selection and consequently only one has been created. This unit has been tested with railways' input data, since no power lines' data was available.

Figure 41: Technical requirements tab: Power lines.

❖ **3. Abiotic impacts tab:** In this tab railways, land use, water and restricted or protected areas are processed. Further documentation can be found in figures (from the 42 to the 46) and the video documentation “5.AbioticImpactsTab.avi”.

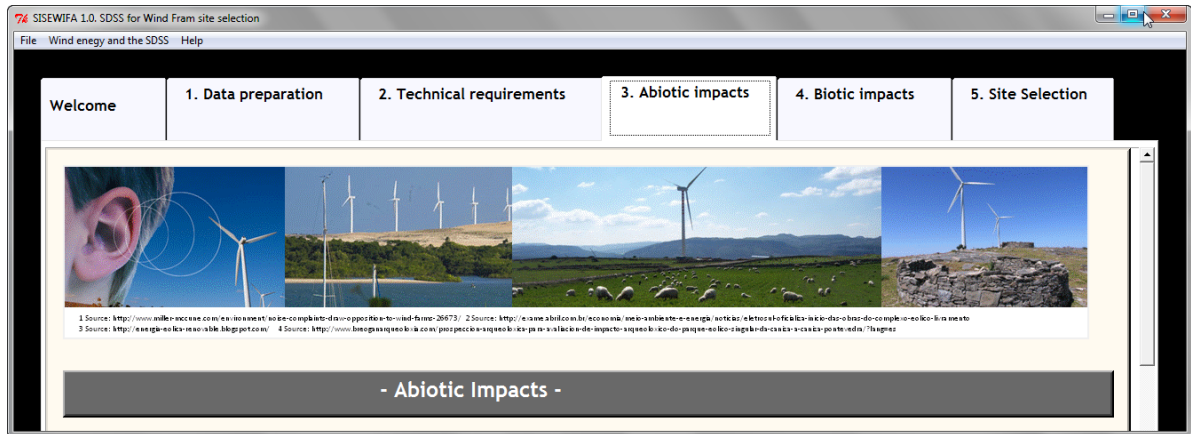


Figure 42: Abiotic impacts tab.

3.1 Railways (figure 43): In this section there is no selection by attributes and consequently the interface becomes simpler.

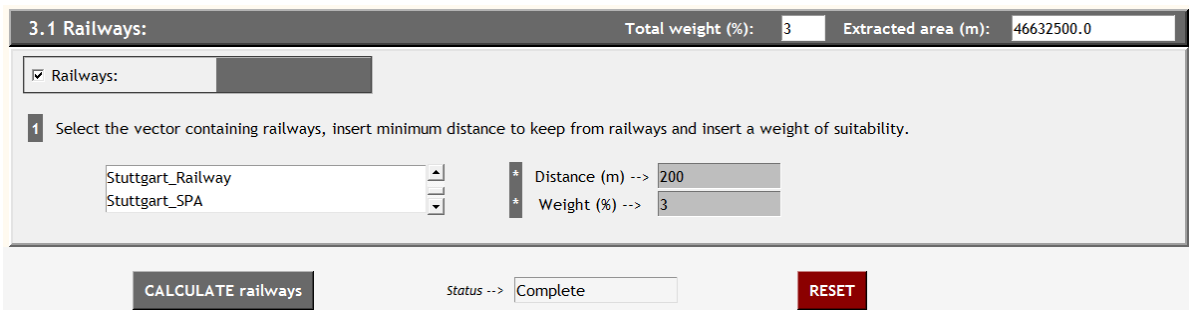


Figure 43 Abiotic impacts tab: Railways.

3.2 Land Use (figure 44): This section offers two possibilities. On the one hand, the first two selections erase selected land uses and their surroundings, while remaining cells obtain the weight distributed where the farther the cell is from buffered areas, the higher is its weight. On the other hand the third selection only assigns full weight to buffered selected uses, while rest of cells obtains value 0.

3.2 Land Use: Total weight (%) 7.0 Suitable area (m): 128730000.0

Land Use (1st selection): Weight (%) = 7 Extracted area (m) = 128730000.0

1 Select ONE vector containing land uses (on the left), click on "Get Fields" and select the field with which land uses will be identified (right).

Stuttgart_Ortslage
Stuttgart_Railway

Get Fields

KLASSE
GN

2 Click on "View Values" and write the expression to select desired uses as shown in the examples.

View Values -->

80001
80001

E.g. One value: "Use" = 'Urban'
E.g. Two values: "Use" = 'Urban' AND "Use" = 'Residential'

Expression --> "KLASSE" = 80001

3 Insert a minimum distances from selected uses, a suitability weight and click on "CALCULATE 1st selection".

* Minimum distance (m) --> 200 * Weight (%) --> 7

CALCULATE 1st selection Status --> Complete RESET 1st selection

Figure 44: Abiotic impacts tab: Land Use.

3.3 Water (figure 45): This section offers two possible selections following the same criteria as in the first selection of land use.

3.3 Water: Total weight: 9.0 Selected area (m): 271562500.0

Water (1st selection): Weight (%) = 9 Extracted area (m) = 271562500.0

1 Select ONE vector containing water bodies (on the left), click on "Get Fields" and select the field with which they will be identified (right).

Stuttgart_gewaesser
Test_Boundary

Get Fields

OBJEKTART
KLASSE

2 Click on "View Values" and write the expression to select desired water bodies as shown in the examples.

View Values -->

103001
103001

E.g. One value: "Order" = 'First'
E.g. Two values: "Type" = 'Stream' AND "Type" = 'Lake'

Expression --> "KLASSE" = 103001

3 Insert a minimum distances from selected water bodies, a suitability weight and click on "CALCULATE 1st selection".

* Minimum distance (m) --> 200 * Weight (%) --> 9

CALCULATE 1st selection Status --> Complete RESET 1st selection

Figure 45: Abiotic impacts tab: Water.

3.4 Protected areas (figure 46): This section offers also two possible selections following the same criteria as in the first selection of land use.

Figure 46: Abiotic impacts tab: Restricted or protected areas.

❖ **4. Biotic impacts tab:** This tab processes three vector inputs of natural protected areas. The geoprocessing workflow is the same than for the land uses but without selecting features. The reason behind is that legislation normally obliges to keep a minimum distance from the entire figure of protection rather than individual elements. Further documentation can be found in figures (47 and 48) and the video documentation “6.BioticImpactsTab.avi”.

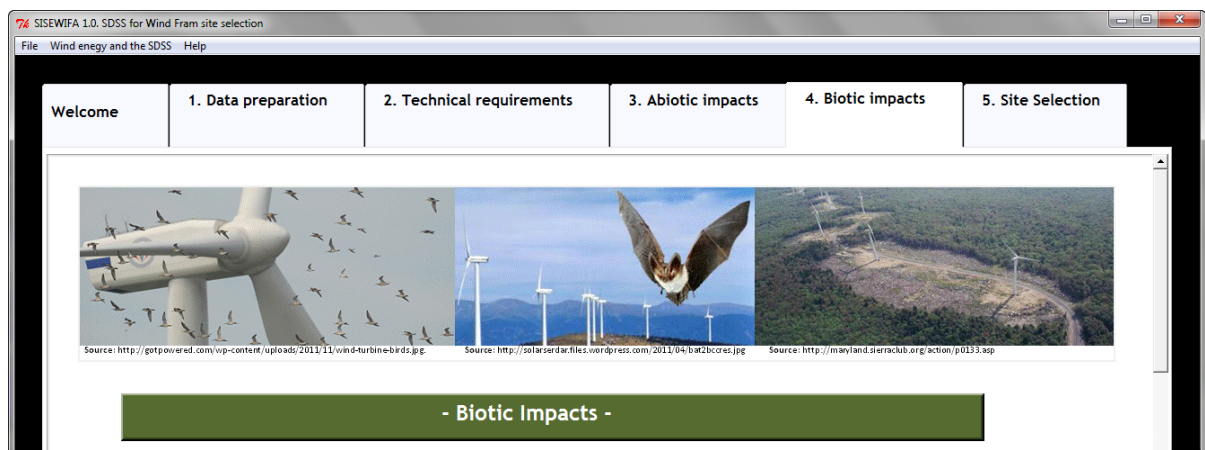


Figure 47: Biotic impacts tab.

Figure 48: Biotic impacts tab: Natural Protected Areas.

❖ **5. Site selection tab:** This tab combines all the rasters inside the “Suitable_Areas.gdb” generating a map which is exported to pdf and automatically open into a map document (mxd). Further documentation can be found in figures (from 49 to 50), table 10 and the video documentation “7.SiteSelectionTab.avi”.

Detailed description:

In order to handle possible errors during the combination of rasters, a system of if-statements and arcpy functions has been applied. For example, when a user performs the whole process of site selection, all the selected criteria are stored in “Suitable_Areas.gdb”. The old rasters are overwritten with the new selections. But if there were no new selections, the old rasters would also be included in the final site selection.

This situation has been avoid as follows; first the script identifies all rasters contained inside this database and detects which check buttons of the interface are currently selected. Then, if none of the buttons of each criterion are checked, the output will be erased; while the output remains intact if there is one button selected. For example, a piece of code included in table 10 shows how the raster of the criterion water is delete if both check buttons are deselected and the raster is in the database.

Table 10 Optional inputs with Pyhon II. This table includes a piece of Python code from the developed desktop application, showing how inputs become optional. On the left the codes are represented as they appear in the Python’s editor IDLE and on the right the comments explaining what the code does. Afterwards the code continues with the processing corresponding to each criterion.

Code	Comment
<pre>if ckbW1 == "no" and ckbW2 == "no": if u'Water_Suitable' in RastersST: arcpy.Delete_management(outSuitabW)</pre>	<pre>## If any of water bodies are selected ## And its output raster is in the database ## Delete the raster</pre>

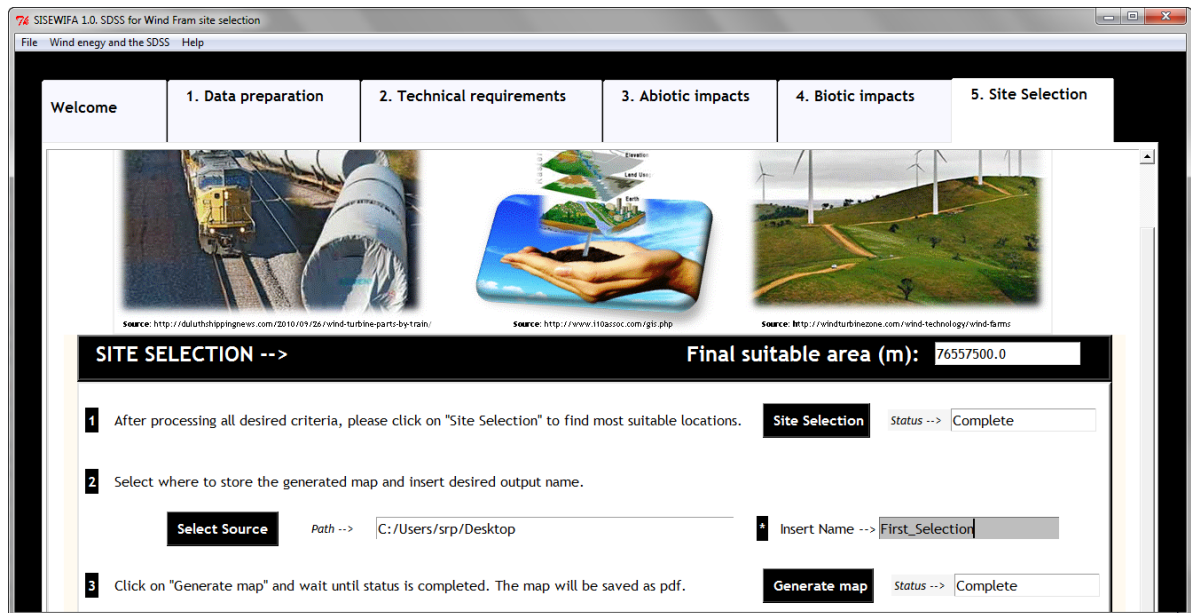


Figure 49: Site Selection tab.

In the second step of this section (figure 49), users indicate the application where they want to store the map and its output name. Then, “Generate map” button invokes the *arcpy.mapping* module to create and execute a map document (*mxd*) with a direct layout view to the generated output, which adopts a predefined symbology. In addition, the map is also exported to pdf.

The main difficulty is how to represent the maps taking into account that the outputs will change depending on the input data and users’ selections. Besides, *arcpy.mapping* has been created to modify existing elements inside map documents or layers, but it does not allow creating new objects (ArcGIS 10 Help). For this reason, an empty *mxd* has been created in order to act as container of the application’s outputs, which includes already a layout design.

Every time the users generate a map, this *mxd* is copied and save with the output name inserted by users. Then, the final output raster is transformed to a layer and inserted in the data frame of the new *mxd*, inheriting the layout.

On the one hand, the page contains element which the code will not edit; a north arrow, a scale bar and the logo of the software. But on the other hand, some changes have been performed in the:

- **Title:** The original title is a combination of two strings; “Suitable locations of wind farms” and “-Selection-“. The code identifies the second string and replaces it by the name inserted by users. This way, the maps exported to pdf will always have an identification, such as name or date of creation.
- **Symbology:** A model layer has been created to represent four ranges of suitability in percentage (0-25%, 25-50%, 50-75% and 75-100%). The new layer is forced to adopt this symbology in order to facilitate comparison between outputs.

- **Legend:** Any layout element of a mxd can be identified by a name which has been used to identify the source image and to fix the legend's characteristics such as size and position. This is required since the legend is distorted when a new layer is added to the layout.

Afterwards, the mxd with the final output is stored in the folder "OutputMxd" of the SDSS application and automatically executed. This way, if users had basic knowledge on ArcMap, they would be able to modify items in the layout of the open mxd.

Furthermore, the mxd is also exported to pdf, adopting the output name inserted in the interface and stored in the path indicated by the users. In this case, the comparison between outputs does not required to manage ArcGIS and it can be easily printed; but the output will maintain the template layout of the original map document. See figure 50.

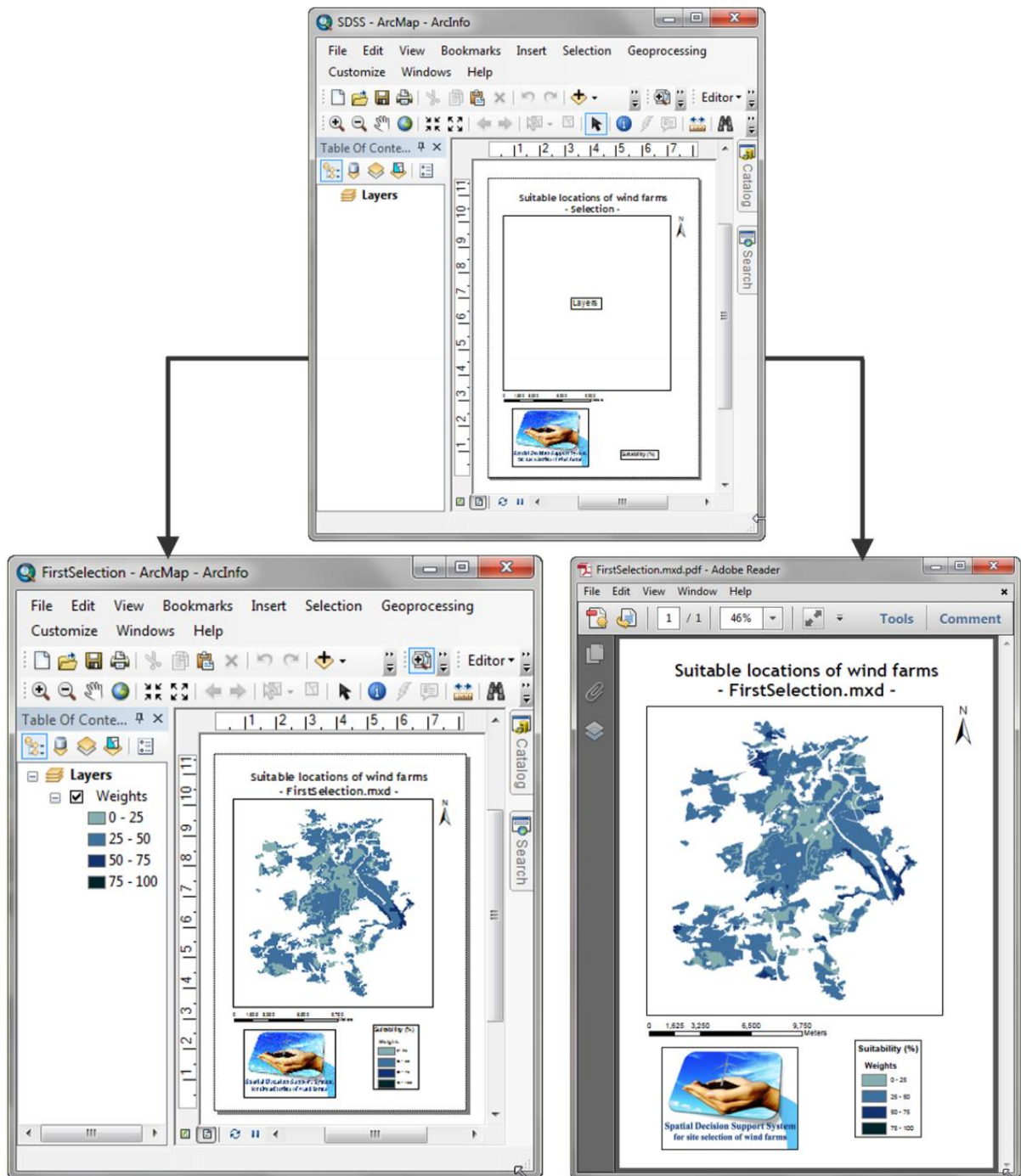


Figure 50: Export of the final output. An empty map document is used to contain the generated output of the final site selection which adopts a predefined symbology and layout. This map is exported to pdf and both, the map document and the pdf, are automatically executed.

9.3 Web application

The purpose of this Web application is to allow the specialists of the UM to perform a site selection of wind farms through their intranet. The GIS services offered by the application are the geoprocessing service in charge of executing the spatial analysis required for the site selection as well as a map service capable of displaying the inputs and the final output.

Although the Web application was intended to be developed on ArcGIS Server for the Microsoft .NET Framework as specified by the LUBW, it has finally been developed on Java due to the difficulties described in section 9.3.3. Besides, the publication of the model has entailed a serial of preparations explained in section 9.3.1. A description of the steps followed for the publication and development of the Web application is given in section 9.3.2.

9.3.1 Preparation of the geoprocessing tasks

Several critical factors must be taken into account when publishing geoprocessing resources:

- 1) **Data types:** The clients indicate ArcGIS Server the inputs to process. Then, the Server processes them in ArcGIS Desktop and sends the outputs back to the client. For these inputs and outputs, not all the data types supported by ArcGIS Desktop are going to be supported by ArcGIS Server because they are not available for lightweight clients such as Web browsers (ArcGIS 10 Help). For instance, raster format is only supported by ArcGIS Desktop and feature class is only supported as output by ArcGIS Desktop, Explorer and Web application clients. Therefore, an analysis of the target clients should be performed when developing the tool.

Although the first model developed for LUBW was only intended to be published in the server, LUBW requested to export it to a Python script and test it with a simple interface as a desktop application. Therefore it was designed to be executed in ArcGIS Desktop and it must be modified in order to publish it on the Server (see next section).

- 2) **Intermediate and output data:** ArcGIS server generates a system of folders so that the same GIS service can be provided to several users at the same time and without generating concurrency problems. During the installation of ArcGIS Server, the job directory is created to store all the data generated by the tasks. In addition, a unique "job folder" is generated every time a task is executed in order to store only the data generated by it (ArcGIS 10 Help). In this manner, the data that is being created for one user does not interfere with the data that is being created for another. Therefore, this folder must be configured to be accessible by all the components of the server.

- 3) **Performance:** Intermediate data has been written to the memory instead of to the disk since thus the processing is much faster and the intermediate data is deleted after executing the task (ArcGIS 10 Help).
- 4) **Data update:** The GIS service has been configured so that only one user at a time is able to update the existing data in order to avoid their locking (ArcGIS 10 Help).
- 5) **Symbology:** If the output data are planned to be draw by the clients, the layer symbologies and symbol types supported by them should be taken into account. In this Web application, the data is draw by a map service, so these issues are not of concern since ArcMap will draw the output with the final locations, transform it to an image and send it to the clients (ArcGIS 10 Help).

9.3.2 Publication and development of the Web application

The Web application will provide the clients with two GIS services: a geoprocessing service and a map service.

In order to publish the geoprocessing service, the model of LUBW must be modified since all the inputs are feature classes which are not supported as model parameters. In this case, the tool “Select Data” from ModelBuilder, which allows users to access all the shapefiles stored in the input database, can be placed at the top of the model. Thus, if the possible selections are transformed to model parameters, then the clients do not directly select a feature class but a string which will be sent to the server in order to indicate which input to process. An example for the submodel of wind resources is given in the next figure.

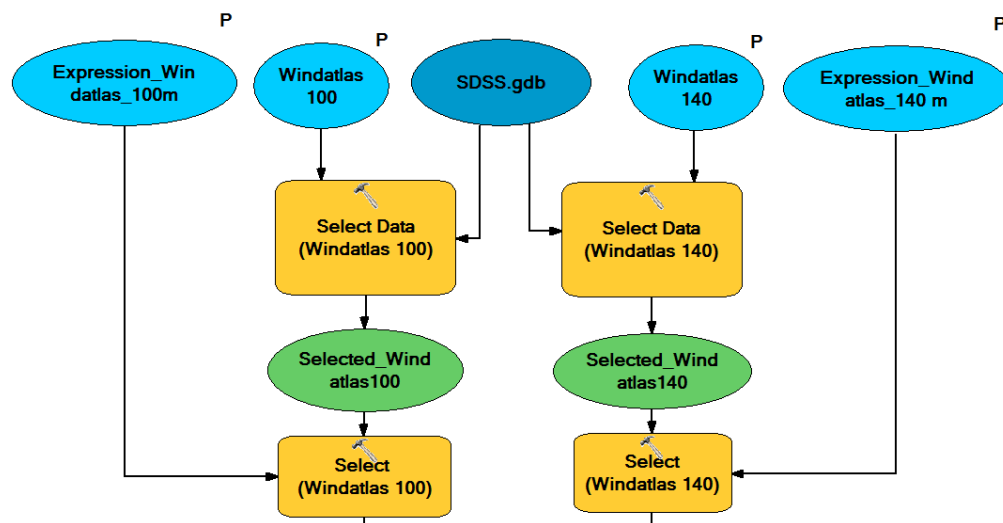


Figure 51: Wind resources submodel for the Web application. This figure represents the modifications applied to the inputs of model 1 (see section 9.1) for their publication in ArcGIS Server 10.

Afterwards, the model is inserted into a map document in charge of displaying its inputs and output, making them accessible to the clients. Then, the map service and the toolbox containing the model can be easily published either through ArcCatalog or the Server Manager.

Finally, the Web application is developed with the Server Manager, which offers a simple and fast method of web application design (see figure 52). The purpose of this Web application was the confirmation that the geoprocessing service can be accessible by the clients. Afterwards a more complex Web application is planned to be developed by LUBW in order to make all the inputs optional, following a similar methodology than the desktop application but in a different developer platform.

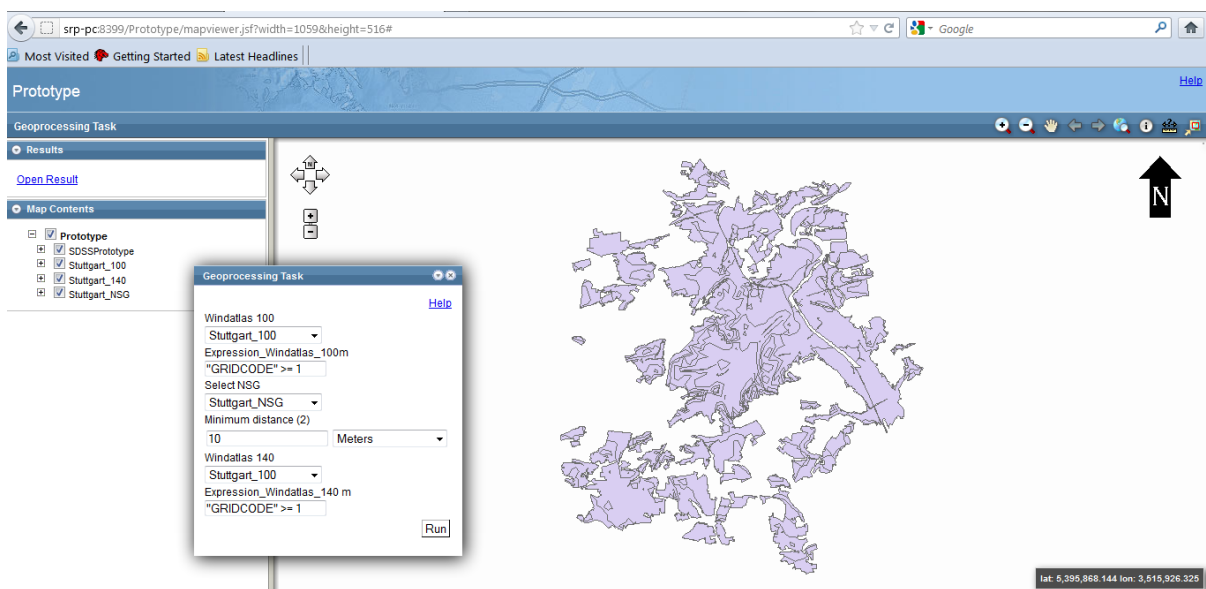


Figure 52: Web application developed with Server Manager. This figure represents a prototype of a Web application including the geoprocessing of the wind resources and the natural protected areas.

9.3.2 Difficulties

The main difficulties have been derived from three different facts: Windows 7 Home Premium is not supported by ArcGIS Server 10, for the Internet Explorer only the versions 7.0 and 8.0 are supported and the Internet Information Services (IIS) were not operative, being required by the framework .NET (ArcGIS Resource Center).

In order to approach a solution, first a virtual machine was created with the software Oracle VM VirtualBox 4.1.10 in order to allow an additional operating system to run in the same machine. Afterwards, Windows XP Professional was successfully installed, which supports ArcGIS Server 10 and the Internet Explorer 7.0 and 8.0. After the configuration of all the software requirements, a strong slow down in the performance of ArcGIS Server was detected and this solution was discarded.

Another approach was the upgrade of Windows 7 to Ultimate with the software “Windows 7 Anytime Upgrade”, which upgrades the operating system without affecting neither the existing data nor the already installed software. ArcGIS 10 was successfully configured although the Server must be accessed through Firefox 3.5 or Google Chrome 4 (ArcGIS Resource Center), since the required Internet Explorers are not supported on this operating system.

Moreover, the IIS were first installed from the control panel and later with the software “Microsoft Web Platform Installer 3.0”, which provides direct download and installation of the components of the Microsoft Web Platform (including IIS) in order to detect possible deficiencies in the system. Although the IIS were installed, the services were not complete operative and consequently the ArcGIS Server for .NET could not be used in the development of the web application.

10. CONCLUSIONS & DISCUSSION

Phase A: Design and development of the SDSSs

ModelBuilder provides an interface where easily build and edit geoprocessing models, being capable of documenting the workflow required to find the most suitable locations for wind farms. Besides, it includes the definition of model parameters which allow the users to automatically generate diverse alternatives according to the input criteria.

The three developed models identify suitable wind resources where none restricted or protected elements are located. In addition, the models 2 and 3 assign percentages of suitability to those areas, reflecting the importance that each criterion has for the users.

Although the distribution of these percentages with the fuzzy membership tool (model 3) shows smaller values of suitability than the model 2, it does not mean that they are less suitable. Indeed, this is a direct consequence of a more accurate representation of the reality since the impacts derived from the installation of wind turbines are always related to the distance. Consequently, a comparison between suitable areas should be performed inside each model and not between models.

On the other hand, the comparison between the three models showed that the more information included in the decision making process, the more chances to find the most suitable location for the wind farms. Thus, the model 3 provides the most accurate analysis. But also the more complex and flexible the model, the more time is required in the geoprocessing and the more model parameters are required. Therefore, the choice between the three models should take into account the needs of the clients. For example:

- For environmentalists, the first model is able to rapidly confirm that a wind project respects all the minimum distances included in the legislation in order to protect natural areas.
- In the case of a Government, the second model could be precise enough to assure that not only the technical requirements are being taken into consideration, but also that the wind farm will have a good acceptance between the citizens because the negatives impacts have been minimized, such as noise or visual impact.
- On the other hand, the model 3 probably will be the best choice for the investors because the more information is analyzed, the more chances to find the most profitable location.

Finally, another issue to take into consideration is that the nature and characteristics of the data have a strong influence in the time of geoprocessing. For example, wind resources in the LUBW's model demand an unnecessary time of processing due to the great number of entities represented by the shapefiles. Since wind resources are a continuous phenomenon, taking the inputs as raster format would have been more convenient. But in case that the inputs must be provided as vector, a possible solution would be the generation of classes before vectorization in order to reduce the number of cell values and consequently the number of created polygons.

Phase B: Development of the desktop application

Python is able to connect Graphical User Interfaces developed with Tkinter to Python scripts generated with ModelBuilder. Therefore, all the models designed in the previous phase could have been programmed to be executed from the GUI of the desktop application.

Although Tkinter provides a platform sufficient to develop GUIs, it showed limitations during the development of the application and in consequence, its functionality needed to be extended with the `tix` module. Other libraries for the development of the interface could have been used, but Tkinter and `tix` were chosen because both are included into the installation package of ArcGIS. Thus, the users do not require additional installations.

After connecting the GUI with the corresponding model, the desktop application adopts the same GIS functionality than the models, being able to access the values demanded by the model parameters with the values inserted in the interface. Moreover, the desktop application was further programmed to extend the functionality of ModelBuilder by making all the inputs optional, offering a more user friendly interface and not demanding knowledge in the involved technologies.

In this manner, the desktop application has been designed to be adaptable to any project related to the site selection of wind turbines. Actually, this application allows the experts on wind energy and environmental sciences to find the most suitable location for wind farms without manipulating the source code or needing to learn ArcGIS. Their expertise is still essential since a deep and long study is needed in order to give a meaningful value to the model parameters. But on the other hand, if these values are documented in a report, any user will be also able to fulfill the application and get the same results.

Furthermore, the desktop application gives to the users the freedom to place the software anywhere in the computer, since the operating system module was successfully applied to locate the paths demanded by all the elements of the application. Actually the application takes 10 minutes to be copied from one computer to another; being completely operative afterwards (it was installed in LUBW and in two additional computers).

As disadvantage, the software cannot be run as a standalone application since the arcpy module is imported into the code, consequently ArcGIS's license is still required and the software must be installed in order to execute the application.

Between the numerous functionality provided by arcpy, the arcpy.mapping module was implemented to manipulate an existing map document to contain the final output of the site selection in order to make it inherit a predefined layout and symbology. Thus, arcpy allows users to export the final output to a map document and a pdf (other formats are also supported such as GIF, JPEG, TIFF or BMP), being easily printed.

Phase C: Development of the Web application

The Web application allows clients to access the same GIS functionality included in the model 1. Thus, the users are able to find the suitable wind resources where no restrictive criteria are located and just through a Web browser. The great advantage is that no ArcGIS license is required to perform the site selection.

But in the case of LUBW and UM, the Web application is intended to be accessed through the intranet of the UM and they are responsible of the costs of the ArcGIS Server license. Therefore, another possibility would have been the direct use of the desktop application since the costs of ArcGIS Desktop license are much smaller and the software takes only 10 minutes to be installed. Besides, the site selection is going to be performed always with their input data which do not required a constant update, consequently the advantage of ArcGIS Server in offering the most up to date data is dismissed.

On the other hand, although the installation and configuration of ArcGIS Server 10.0 generated many difficulties, ArcGIS Server allowed a fast publication of the GIS resources and a fast development of the Web application.

11. RECOMMENDATIONS

Although ModelBuilder itself optimizes the spatial analysis due to the arrangement and automation of tools, a further study could be performed in order to speed up the processing. For example:

- Writing features classes and tables to the memory is often faster than writing them directly to the disk, since they become temporary and they are deleted when the application is closed (ArcGIS 10 Help).
- A careful analysis of the time of processing per tool can also be performed when running the entire model, trying to find alternatives in the parts where the model requires longer time.

Besides, a specific layout for the output of each criterion could be designed in order to provide users with additional information. The difficulty lays on the incapacity of `arcpy.mapping` to create new objects. Therefore, the outputs must adopt a predefined symbology. In the case of the final suitable locations, design an appropriate symbology is easy because the scale of suitability always varies from 0 to 100. But in the case of an individual criterion this is impossible to predict. For instance, while a company might assign a value 60 to wind resources, environmentalists might give them only 15.

A possible solution could be the design of different symbologies according to a maximum percentage of suitability. Afterwards, an `arcpy` function can detect the maximum in the output and a Python statement can assign it to an appropriate symbology.

Moreover, the functionalities of the desktop application could be further extended to provide users with more flexibility. For example, increasing the number of criteria and possible selections or developing more complete menus including images and documentation related to the field of knowledge.

Finally, since the developed Web application only includes the functionalities of the model 1, a more complex Web application could be developed to make also the inputs optional. The methodology could be similar to the one applied in the desktop application but the developing framework must be different. For instance, using the Application Programming Interfaces offered by ArcGIS Server.

ANNEX I: Spatial analysis performed in ModelBuilder

The three models designed in ModelBuilder have been divided into submodels so that they are easier to analyze, manage, correct and reuse as scripts during the applications' programming. An explanation of the geoprocessing workflow applied to each submodel as well as their combination is given in the following pages, accompanied by screenshots of the ModelBuilder's interface (from figures 54 to 93).

In these figures, different sections can be observed; separate sections where each input (vector or raster) generates an output and a global section where those outputs are combined into the final output of the model (indicated by a black text box).

On the one hand, the individual outputs containing only the areas to exclude are indicated by a red text box. On the other hand, the individual outputs containing only suitable areas or a combination of areas to include and exclude (some submodels process both together in order to speed up the time of geoprocessing) are indicated by a blue text box. See figure 53.

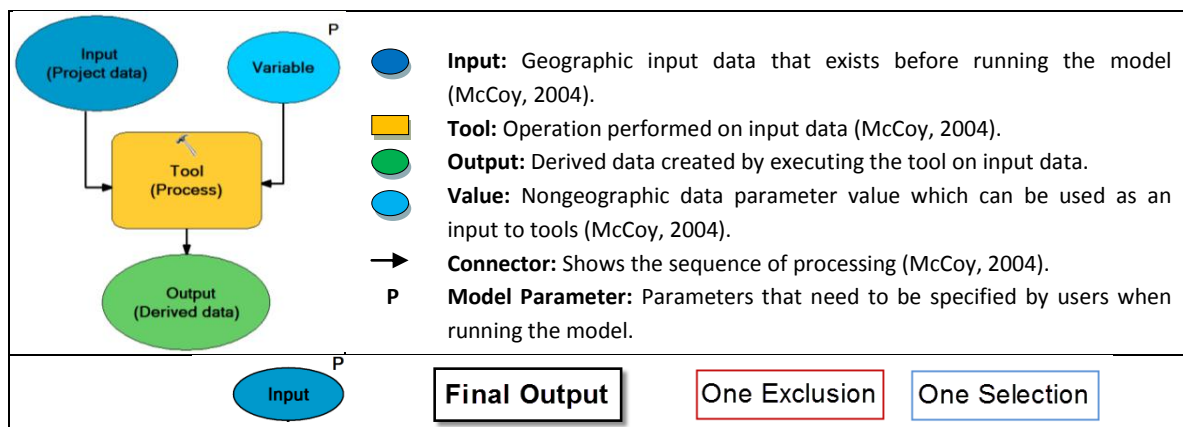


Figure 53: Symbols used inside the models.

1 Wind Resources

Wind resources are one of the most important factors to ensure the viability of a project (Tong, 2010). Since the most suitable resources depend on the area of study, turbines' technical characteristics and height of exploitation, an evaluation should be done individually for each project.

An identification of the areas with profitable wind speeds is essential in the spatial analysis. A project becomes unfeasible if a wind park is installed in regions where the speeds do not reach the minimum for which turbines start to produce energy or where they are too high that they must be switched-off in order to avoid mechanical damages.

Each of the three models presents a different approach for the selection of wind speeds.

Model 1 (figure 54): The LUBW model requires the selection of a profitable range of speeds at 100 and 140 m height above ground level, regardless of how appropriate each speed is within that interval. Consequently, the spatial analysis consists on the combination of two selections performed to the input wind atlases at those heights.

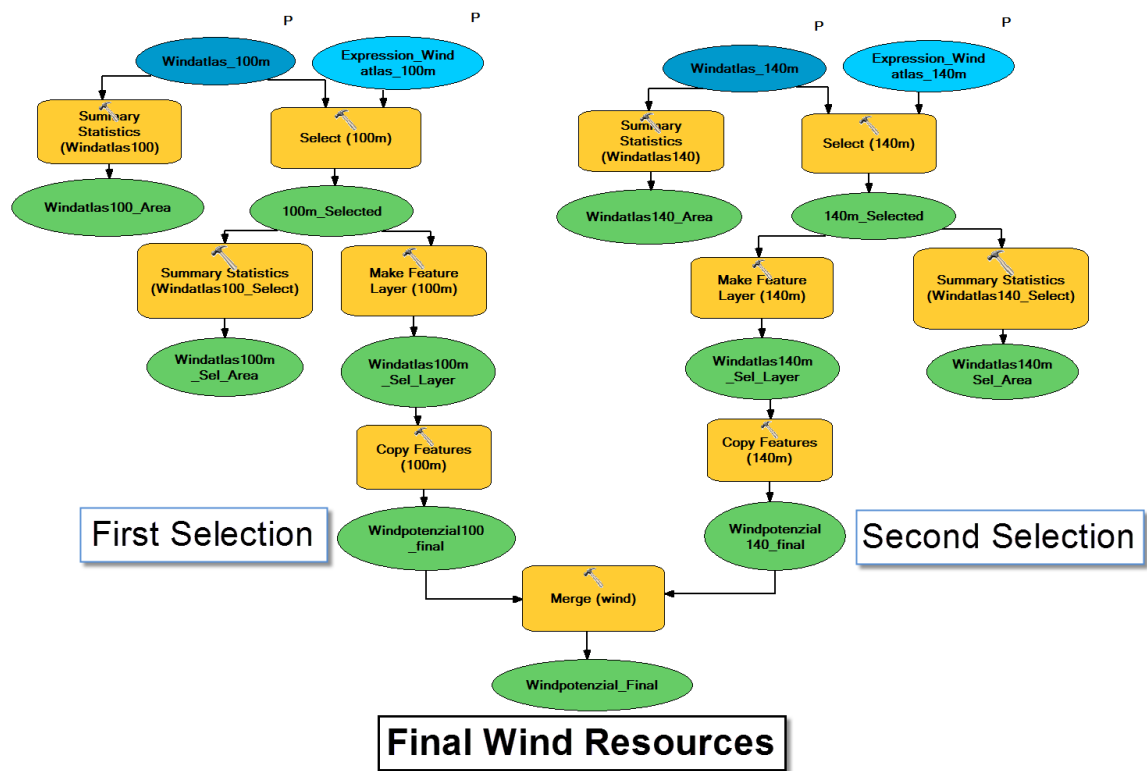


Figure 54: Wind Resources in model 1. This model processes two vectors (wind atlases at 100 and 140 m height) which are combined generating an output vector with suitable wind speeds. It has been designed according to the specifications of LUBW.

Both input vectors are processed as follows:

- 1) **Select by attributes:** Two attribute queries introduced by users (Expresion_Windatlases) select suitable wind resources at 100 and 140 m height.
- 2) **Summary statistics:** This tool calculates statistics for a field in a table. Calculating the sum of all input areas before and after the attribute query, makes possible realize how much area is reduced with the specified selection.
- 3) **Make feature layer:** Creates a temporary layer with which a selection can be manipulated without affecting original data (ArcGIS 10 Help).
- 4) **Copy features:** Used in order to copy and stored selected features from the temporary layer to a permanent feature class (ArcGIS 10 Help) with which geoprocessing will continue.

Afterwards, the generated outputs are combined with a geometric overlay performed by the tool “Merge”, generating an output vector from which following restriction criteria are erased. See schema in the following sketch.

Model 2 (from figures 55 to 57): Users are allowed to select the most convenient wind speeds for a concrete project and assign them a weight which will indicate their grade of importance in the final site selection. The users can perform four selections, either resources at different heights or ranges of speeds, and assign a weight to each selection. The entire model is represented in figure 55 and two zooms in are given in figures 56 and 57.

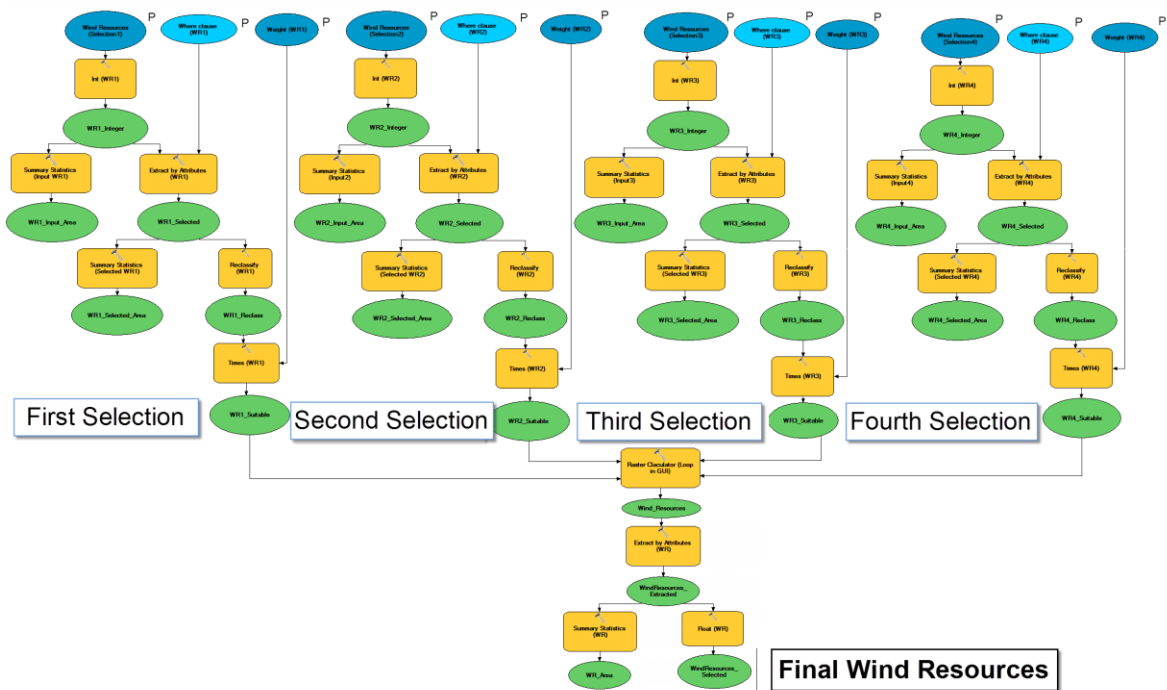


Figure 55: Wind Resources in model 2. This model processes four rasters, which generate four different outputs containing selected wind resources with assigned weights. Afterwards, these outputs are combined in a raster, representing the total selected wind resources. Figure 56 and 57 represent a zoom in of this model.

Each input raster will be processed as followed:

- 1) **Int:** Rasters’ cell values are either integer or floating-point. The integer rasters can store cell values in tables known as Value Attribute Table (VAT), which contains at least one column with possible values and another with the count of cells containing each value. In contrast, these tables are not available for floating-point rasters because of the great number of unique values that they might contain (ArcGIS 10 Help). Therefore “Int” guarantees that all the input rasters contain a VAT table where users can indicate which attributes (in this case wind speeds) to select.
- 2) **Summary statistics:** Since it calculates the statistics for a field of a table, also a VAT is needed for this tool. It has been set to count the number of cells in a raster, generating a table where the

statistic is stored. Afterwards, the desktop application has been programmed to generate a search cursor which reads inside this table and extracts that value in order to multiply it by the cell area. The final aim is letting users notice the reduction of available surface on the input by their restrictions (selections). Thus, the inputs parameters could be changed in the submodels if needed, before processing the final site selection model. For this reason, "Summary statistics" is used in all the models.

- 3) **Extract by attributes:** While "Select by attributes" is the tool applied to input vectors, "Extract by attributes" is the equivalent for rasters, selecting suitable speeds by a logical query known as where clause.
- 4) **Reclassify:** After extraction, the output raster contains the extracted cells with their corresponding values and the rest with NoData. In following steps, the "Raster calculator" tool will add the outputs of the four selections. Then, if a cell with NoData is added to a cell with a concrete value, the output cell will be classified as NoData and excluded from suitable resources. Ergo, a reclassification is essential to include all resources selected by the users, transforming the extracted values to 1 and NoData to 0.
- 5) **Times:** This tool gets the suitability weights inserted by the users as model parameters and multiplies the four outputs by their corresponding weights. As result, those cells with value 1 obtain their weights of suitability while cells with value 0 remain the same, not having any effect.

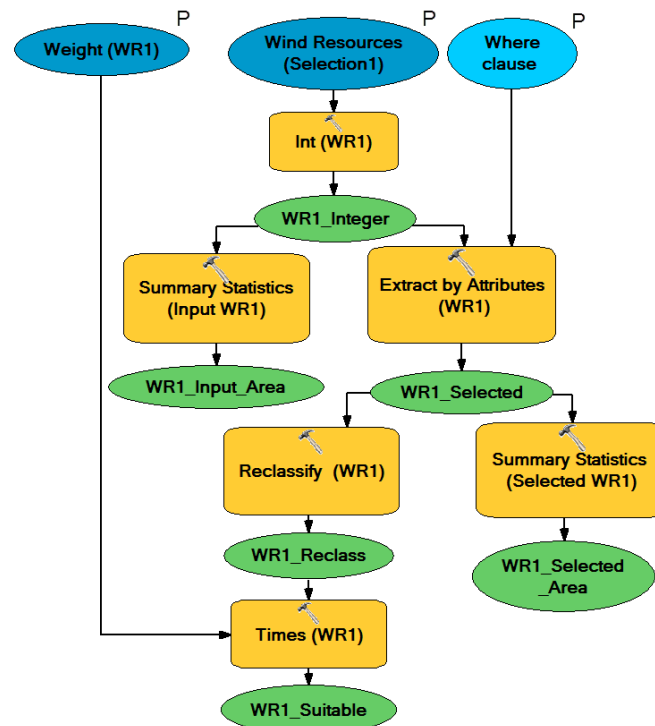


Figure 56: First selection of Wind Resources in model 2. Geoprocessing applied to each raster input.

Resulting four outputs are combined as follows:

1. **Raster calculator:** Adds cells with the same coordinates. The resulting raster represents suitable wind resources which cells carry the addition of all the corresponding weights and cells with value 0 which indicates that any selected wind speed can be found in that location. As an example, the cells where wind resources are profitable at different heights and different speeds will indicate greater suitability than those areas with only one option.
2. **Extract by attributes:** The where clause selects and extracts all the cells with value greater than 0, generating a raster with only the weighted suitable wind resources. Areas without suitable resources are classified as NoData and consequently they will be automatically erased from the rest of criterion considered in site selection.
3. **Summary statistics:** Applied to calculate the total selected area of wind resources.
4. **Float:** This tool transforms integer rasters into floating-point. Since some rasters are generated as floating during the geoprocessing and their conversion to integer might lead to a loose of information, most calculations are done as floating-point rasters.

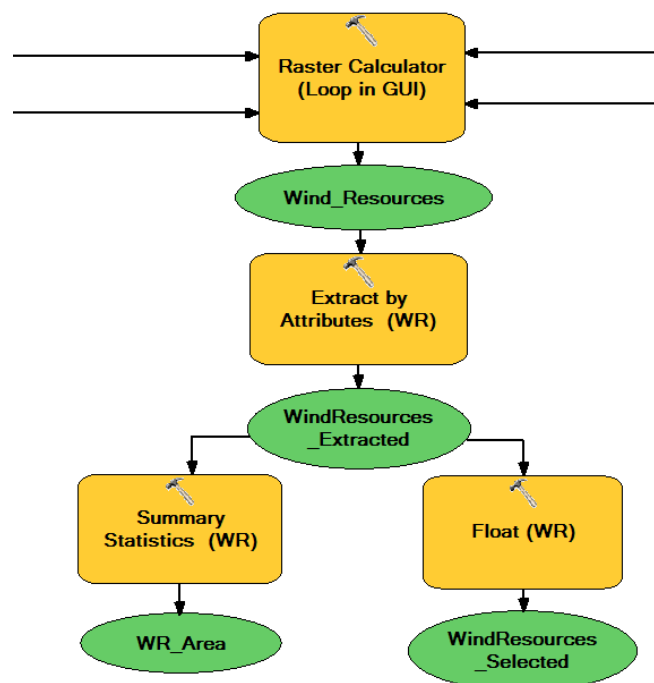


Figure 57: Calculation of final Wind Resources in model 2.

ModelBuilder allows specifying the processing extent, a rectangle specified by coordinates where raster processing is going to occur (ArcGIS 10 Help). This makes geoprocessing tools to process only the area of study avoiding unnecessary spatial analysis. Furthermore and essential, it limits output rasters to that extend. If raster with different extends were added in “Raster calculator”, there would be a loose of information. Consequently, processing extend for all rasters in model 2 and 3 has been determined by the output raster of Wind Resources in model 2 and 3 respectively.

Model 3 (from figures 58 to 61): In contrast to model 2 where a selection of wind speed would receive the same weight, this model assigns full weight to highest speeds and decreases proportionally until the smallest speeds. Consequently, the higher speeds which produce more energy will have higher weight in the final site selection than those which generate just energy enough to compensate costs of operation.

Next sketch represents the entire submodel in order to give a general idea about the workflow. Due to its dimension and difficulty to read, two zooms in can be found in figures 60 and 61.

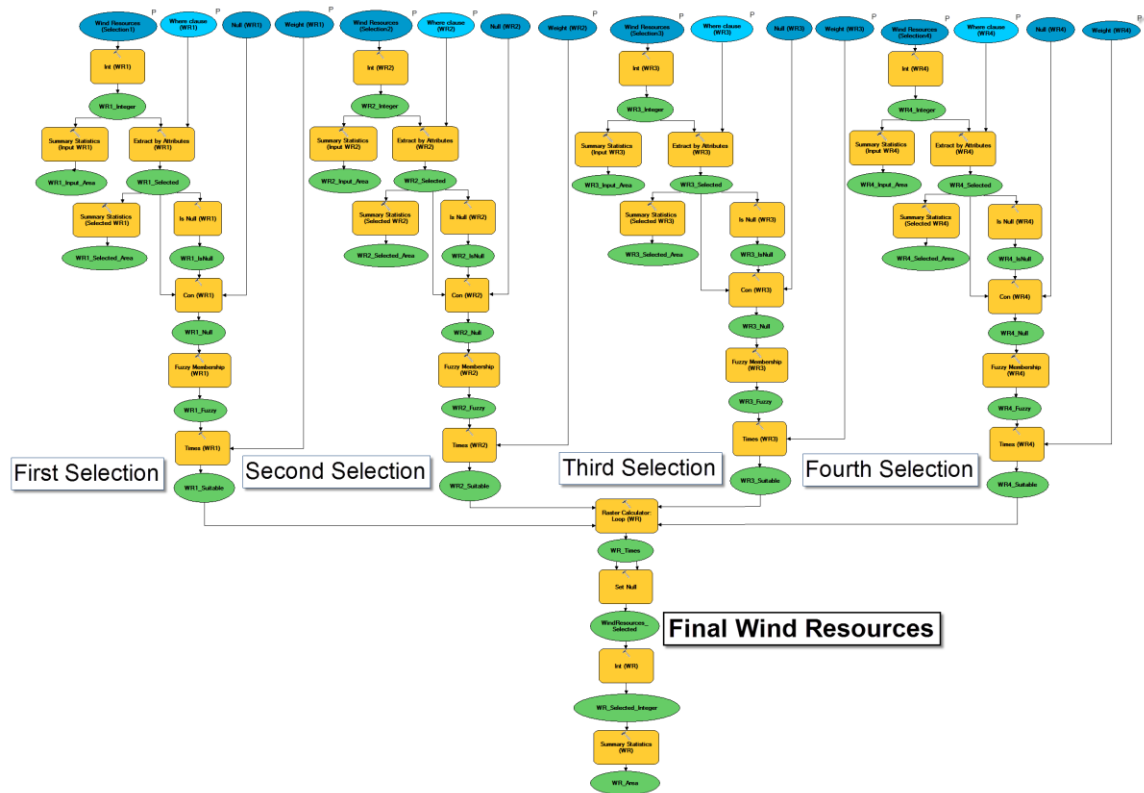


Figure 58: Wind Resources in model 3. This model processes four rasters, which generate four different outputs containing selected wind resources with assigned weights. Afterwards, these outputs are combined in a raster, representing the total selected wind resources. Main difference with model 2 is the fuzzy membership. Figures 61 and 60 represent a zoom in of this model.

Each input raster will be processed as followed:

- 1) **Int:** As model 2.
- 2) **Summary statistics:** As model 2.
- 3) **Extract by attributes:** As model 2 (see figure 59).
- 4) **Is Null:** Resulting raster of “Extract by attributes” contains cells with wind speed values and cells with NoData. As in model 2, NoData cells must be reclassified as 0, but in this case rest of cells need to maintain original values in order to apply a fuzzy distribution of weights. Consequently, a sequence of two tools is used instead of “Reclassify”; “Is Null” and “Con”. First, “Is Null” generates a raster where NoData cells are identified and assigned value 1, while the rest obtain value 0.

5) **Con**: Afterwards, “Con” performs a conditional if/else evaluation on the output from “Is Null” tool. If cell values are 1, they will be transformed to 0; otherwise (else) cell values will recover the original values that they had in the output of “Extract by attributes” tool. An example of these tools is showed in figure 59.

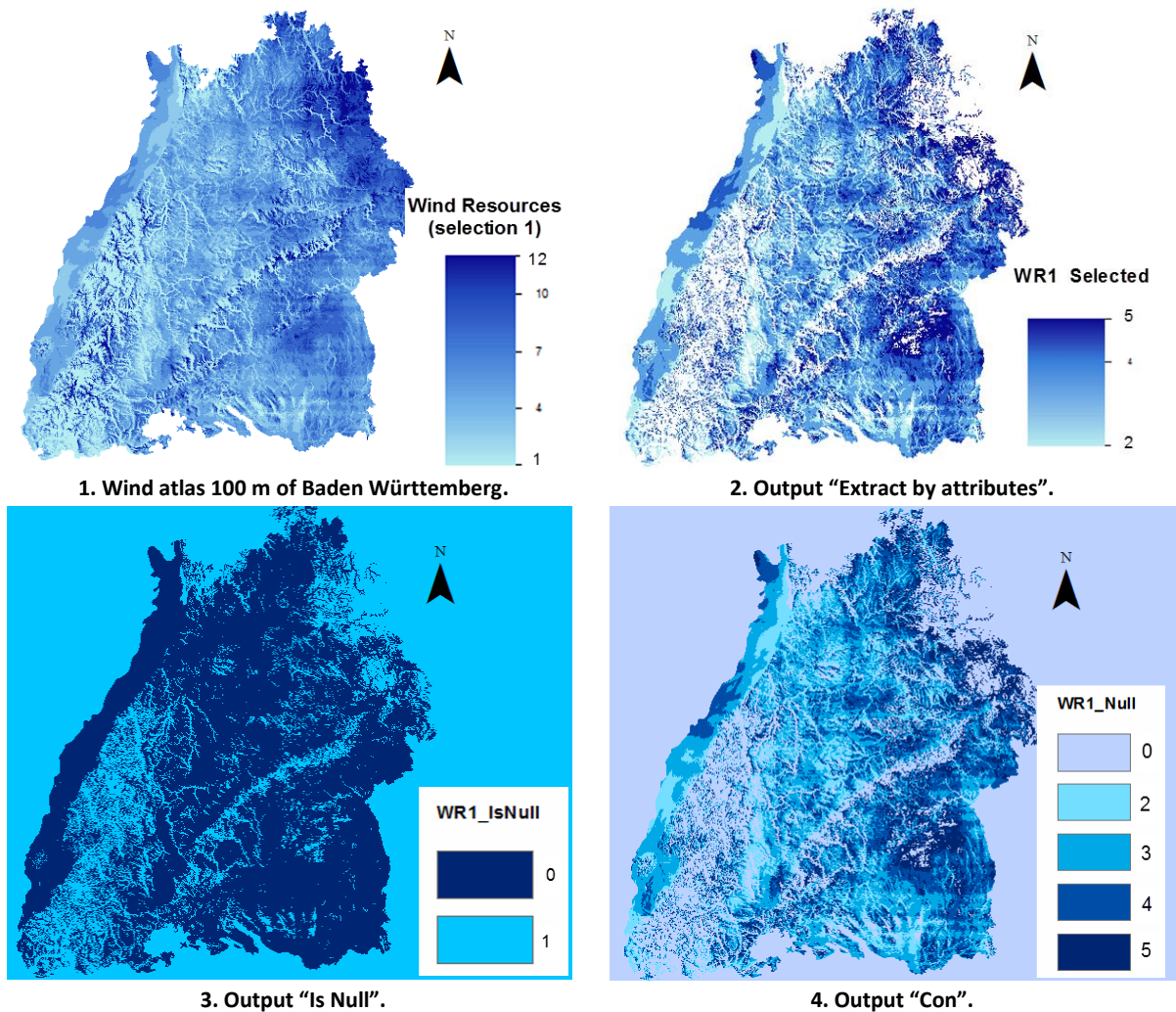


Figure 59: Intermediate outputs of Wind Resources in model 3. Image 2 shows the results after an extraction applied to Wind atlas 100 m (1). Afterwards it is processed with “Is Null” (3) which assigns cells with NoData a 1, and 0 to rest of cells. The tool “Con” changes ones to zeros while keeping original values (raster shown in 2) for those cells with value 1.

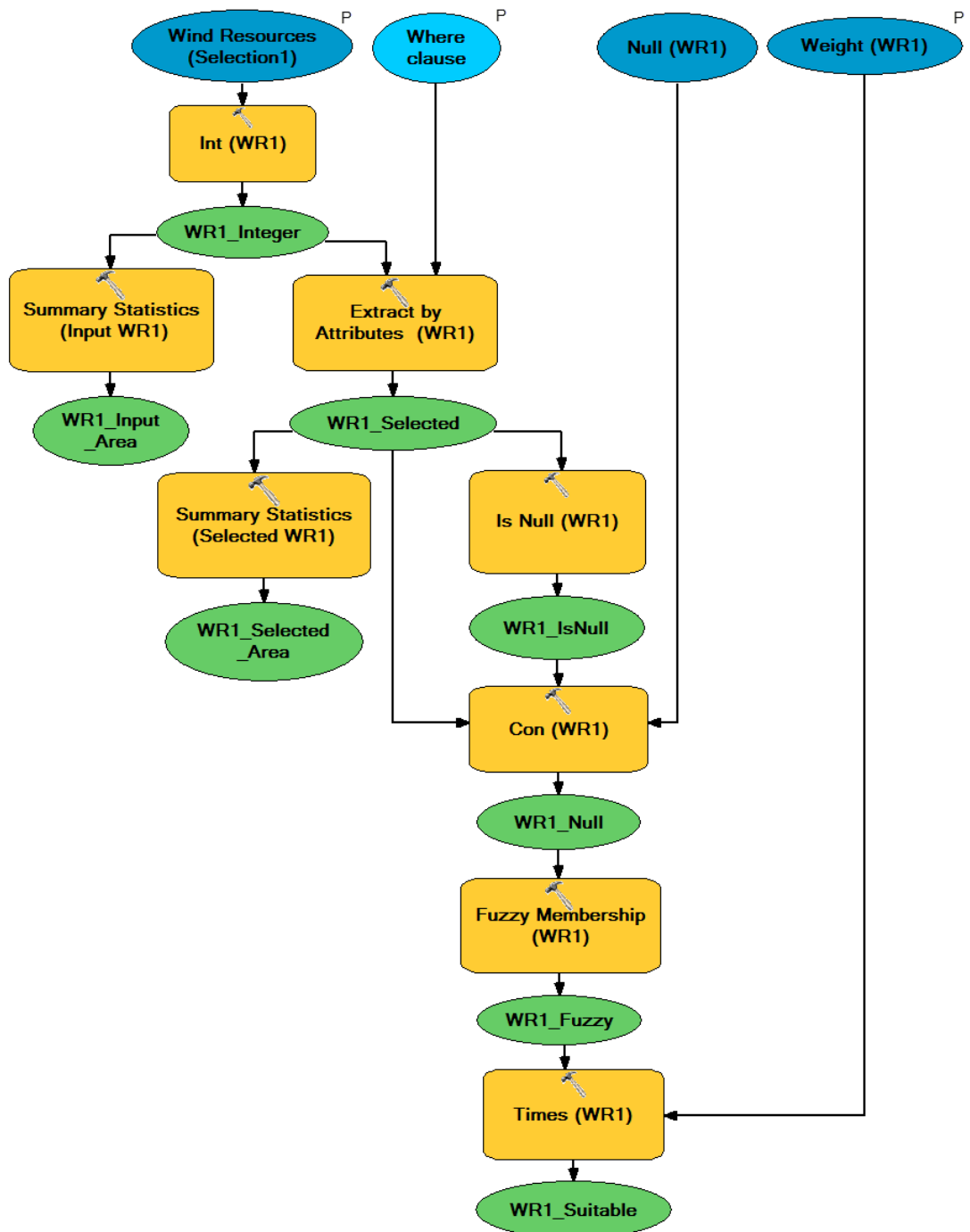


Figure 60: First selection of Wind Resources in model 3. Geoprocessing applied to each raster input.

- 6) **Fuzzy Membership (linear with positive slope):** While energy production increases from cut-in to rated wind speeds, potential power reaches the maximum output at rated speeds keeping same production until the cut-out (see section 3.2.1). Therefore, the second range of wind speeds is economically more suitable than the first one.

This model allows a distribution of weights proportional to wind speeds by applying fuzzy membership. First, users select wind resources and assign them a weight. “Fuzzy membership” reclassifies those wind speeds to a 0 to 1 scale applying a positive slope linear transformation between a specified minimum and maximum values. While any value below the minimum obtains value 0 indicating none suitability, everything above the maximum obtains value 1 carrying maximum suitability (ArcGIS 10 Help).

- 7) **Times:** Afterwards, the output from “Fuzzy Membership” needs to be multiplied by the weight. As result, while cells with value 1 obtain directly full weight, the rests of the cells are assigned a weight which decreases proportionally to their speed until 0, where no suitable resources can be found.

Resulting four outputs are combined in “**Raster calculator**” as in model 2 (see figure 61). Afterwards, “**Set Null**” transforms all cells with value 0 into NoData in order to be erased from the rest of criteria. The output will be the final suitable wind resources raster. Finally, “**Int**” transforms this raster to integer in order to generate a VAT where “**Summary statistics**” can calculate the total count of cells and derive the final area.

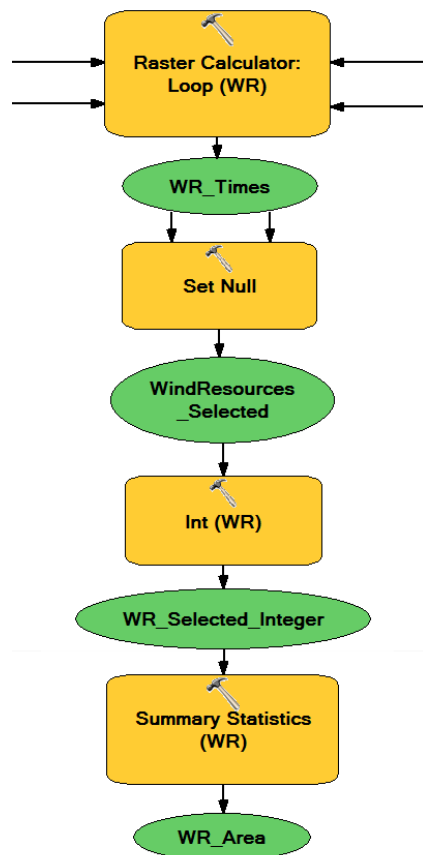


Figure 61: Calculation of final Wind Resources in model 3.

2 Slopes

Slopes greater than 17° are likely to generate turbulences, which might be transferred to superior layers of air changing wind direction and hitting turbines' blades with a not profitable angle. Consequently, terrains with certain degrees of slope are more suitable than others depending on the characteristics of the project. Slopes are not considered in **model 1**.

Model 2 (figure 62 and 63): This model selects terrains with slopes smaller than an input value ("No Suitable Slopes Value") and assigns them an inserted weight increasing their suitability in the final sitting. Rests of slopes maintain a weight 0 but they are not erased, since a feasible wind park can still be located depending on the project. Next sketch documents the workflow.

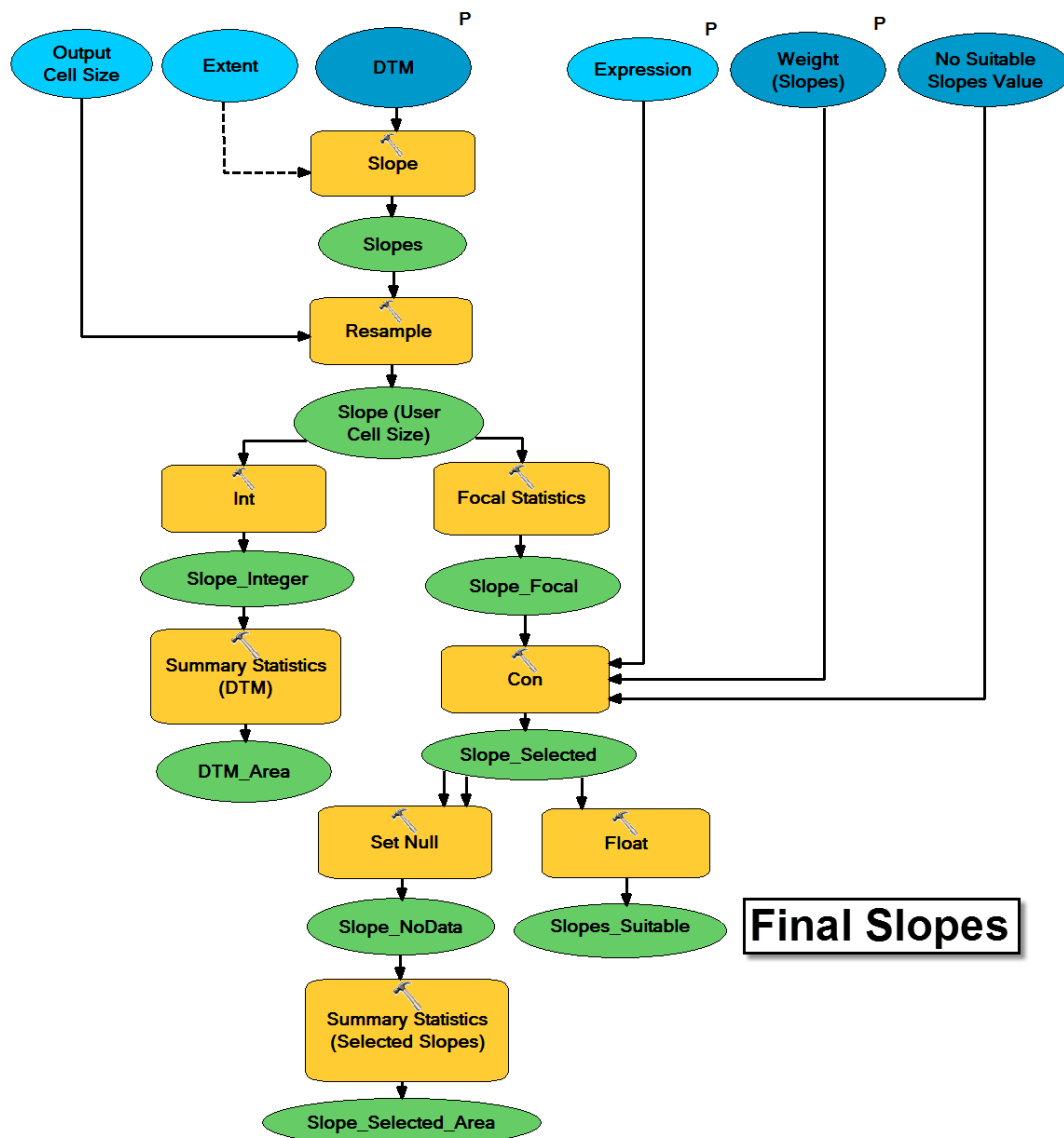


Figure 62: Slopes in model 2. This model processes a DTM in order to generate and select suitable slopes.

- 1) **Slope:** Applied to calculate the slopes from an input DTM which contains the elevation data of the terrain. It would be processed only for the extension of the output of wind resources in model 2 to avoid unnecessary processing. This tool identifies the rate of maximum change in height (slope) generating a raster where each cell represent a slope value as degree or percent. In this application the slope is processed as degree.
- 2) **Resample:** This tool guarantees that the raster generated from the DTM has the same cell size as the output of wind resources in model 2, which will be used during all the application. Inputs cells are resample by a bilinear algorithm.

On the one hand, the nearest neighbor would be the best option if “Resample” were used after “Extract by attributes”, since it is the fastest technique and all the extracted cells are assigned the same value (weight) in this model, therefore there is no loose of information. But in order to inform users about the decrease of suitable area after applying slope’s restriction, areas must be calculated before this tool, ergo resampling must be performed here and consequently nearest neighbor is not appropriate.

On the other hand, bilinear and cubic interpolations are adequate for continuous data. While bilinear causes smoothing of the data, cubic might generate values outside the range and requires more processing time (ArcGIS 10 Help), accordingly bilinear has been applied.

- 3) **Int:** The output of “Slope” needs to be converted to integer in order to obtain a VAT table where “Summary statistics” is able to calculate areas.
- 4) **Summary statistics.**
- 5) **Focal statistics:** Relative flat areas with slopes smaller than a threshold avoid turbulences and assure that wind speed increases with height, where turbines can extract their kinetic energy. If selection is performed directly on the output of “Slopes”, an individual cell with slope under the threshold will be considered as suitable even when neighbor cells are not suitable. Therefore, this will increase suitability in that area even if turbulences might appear.

“Focal statistics” is required to avoid this case, smoothing the resample slope raster (see figure 63) by calculating the maximum change in height relative to a specified neighborhood; while “Slopes” calculates the change of height for each cell to its direct neighbors. For this application a neighborhood of 50X50 (cell units) and a maximum statistics have been applied.

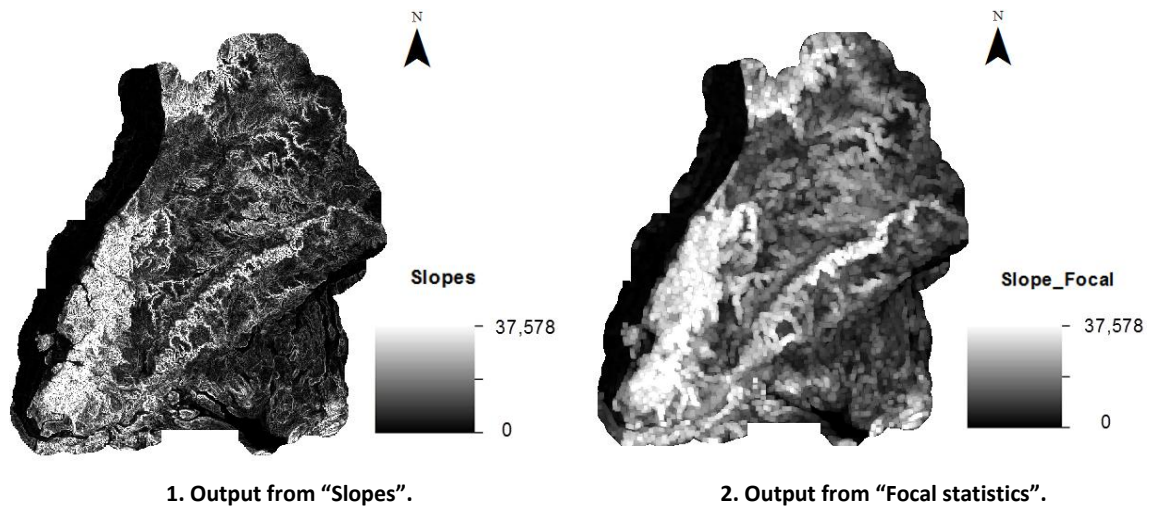


Figure 63: Intermediate outputs of Slopes in model 2. Output raster (2) after smoothing the raster slopes with "Focal Statistics" tool.

- 6) **Con:** Used to select suitable slopes. If the cell values are smaller than the input threshold (model parameter: Expression), they will obtain an input weight; otherwise (else) the cells will carry value 0. As a result, not selected slopes do not increase suitability in the final site selection, considering that the construction might be more expensive in steep areas or turbulences might force wind to hit some turbines' blades with an unprofitable angle. But they are not erased because the wind parks must still be feasible, depending on the rest of criteria.
- 7) **Float:** Previous output is transformed to floating-point generating the final output of this submodel.
- 8) **Set Null and Summary Statistics:** Used to transform 0 values (no selected) to NoData in order to calculate the area of suitable slopes with "Summary Statistics".

Model 3 (figure 64): A fuzzy distribution of weights generates a raster where the more even the terrain is within selected slopes, the higher the weight assigned; and on the contrary, the steeper the slope, the smaller the weight.

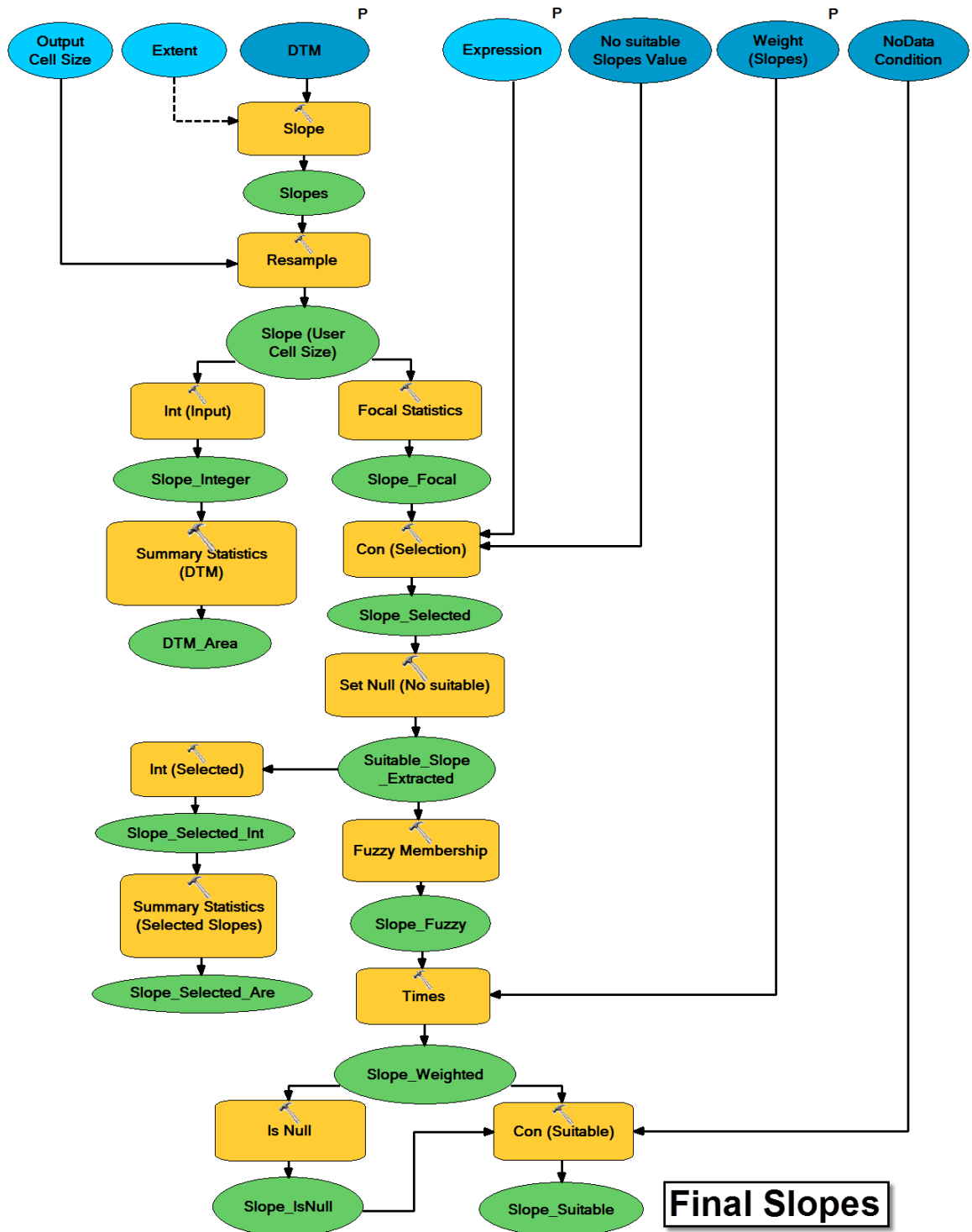


Figure 64: Slopes in model 3. This model processes a DTM in order to generate and select slopes.

First steps are the same than in model 2.

- 1) **Slope.**
- 2) **Resample.**
- 3) **Int.**
- 4) **Summary statistics.**
- 5) **Focal statistics.**
- 6) **Con:** A difference with model 2 lay on reclassification. If cell values are smaller than an input threshold (maximum slope) they will be transformed to 1 while the rest will obtain a symbolic value of 1000. The aim of this transformation is to classify no suitable slopes as NoData (in next step) so that their values do not interfere in the linear transformation processed by “Fuzzy membership”.
- 7) **Set Null:** Used to transform those cells with 1000 value into NoData.
- 8) **Int.**
- 9) **Summary Statistics.**
- 10) **Fuzzy membership (linear with negative slope):** Reclassifies slopes to a 0 to 1 scale applying a negative slope linear transformation between a specified minimum and maximum slope values. In this case, the cells containing the smallest slope acquire value 1 (maximum suitability) and the rests of the cells decrease in value until 0, proportionally to the slope’s increase. If none suitable slopes have not been reclassified as NoData in previous steps, they would have been assigned value 1 altering the linear transformation.
- 11) **Times:** The inserted weight is then distributed in the output of “Fuzzy membership” proportionally to the slope. After this step, the cells with smallest slopes carry full weight instead of the value 1.
- 12) **Is Null:** NoData cells are identified and assigned value 1 while the rest of cells obtain value 0.
- 13) **Con:** NoData is reclassified as 0 so that they are not erased from the final suitable areas.

3 Roads

Turbines cannot be built on roads or their closest surroundings because of safety reasons. Therefore, these areas must be erased from the final selection. On the other hand, if wind parks are built too far away from roads, the cost of construction and maintenance might be too high. Besides the roads’ characteristics must be taking into consideration since several transportations would be needed during turbines’ life-cycle.

Model 1 (figure 65): Considers a minimum distance from roads which will be erased from suitable areas.

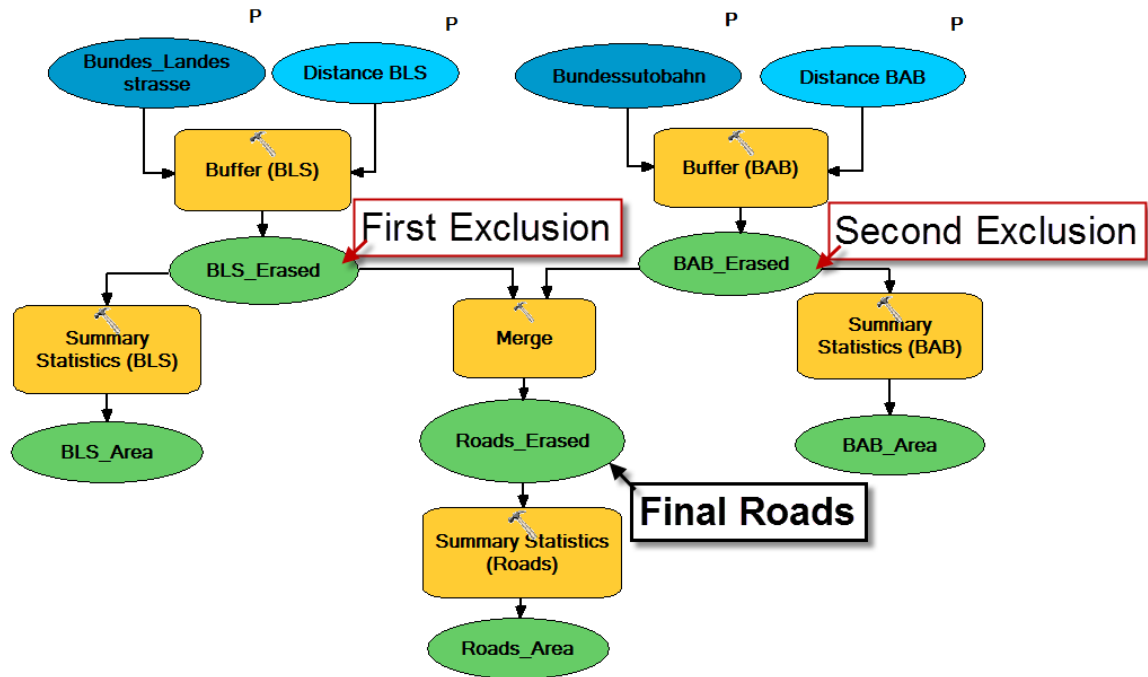


Figure 65: Roads in model 1. This model processes two vectors which are combine generating an output vector containing roads and their surroundings according to minimum distances inserted by users. It has been designed according to the specifications of LUBW.

- 1) **Buffer (Full, Round, All):** A polygon is created around all the features (roads) of the two input vectors containing the national and federal roads in order to erase them and their surroundings from the final suitable areas.

“Buffer” has been configured to generate polygons around the input features on both sides (full). If the roads are represented as lines, the side type full will generate a buffer on both sides of each line. And if they were represented as polygons, the buffer would be generated around each polygon containing and overlapping the area of the input features (ArcGIS 10 Help). In the case of the line features, buffers are also shaped as a half circle at ends of lines (end type: round).

All the buffers are also dissolved into a single feature (dissolve type: all) removing any overlap (ArcGIS 10 Help) in order to speed up rest of the geoprocessing.

- 2) **Summary statistics:** Indicates buffered area which will be erased from the suitable areas.
- 3) **Merge:** Combines the buffered roads into a single output vector (final roads).

Model 2 (from figure 66 to 68): On the one hand, the users are able to select suitable roads and generate a buffer around them with safety purposes. As consequence, the selected roads and their surroundings are erased from the final suitable areas. On the other hand, the areas which are close enough to the selected roads are assigned a weight to increase their suitability, since installing a wind farm close to an appropriate transportation network decrease considerably the required budget.

The next sketch represents the entire submodel in order to give a general idea about the workflow. Due to its dimension, two zooms in can be found in figures 67 and 68.

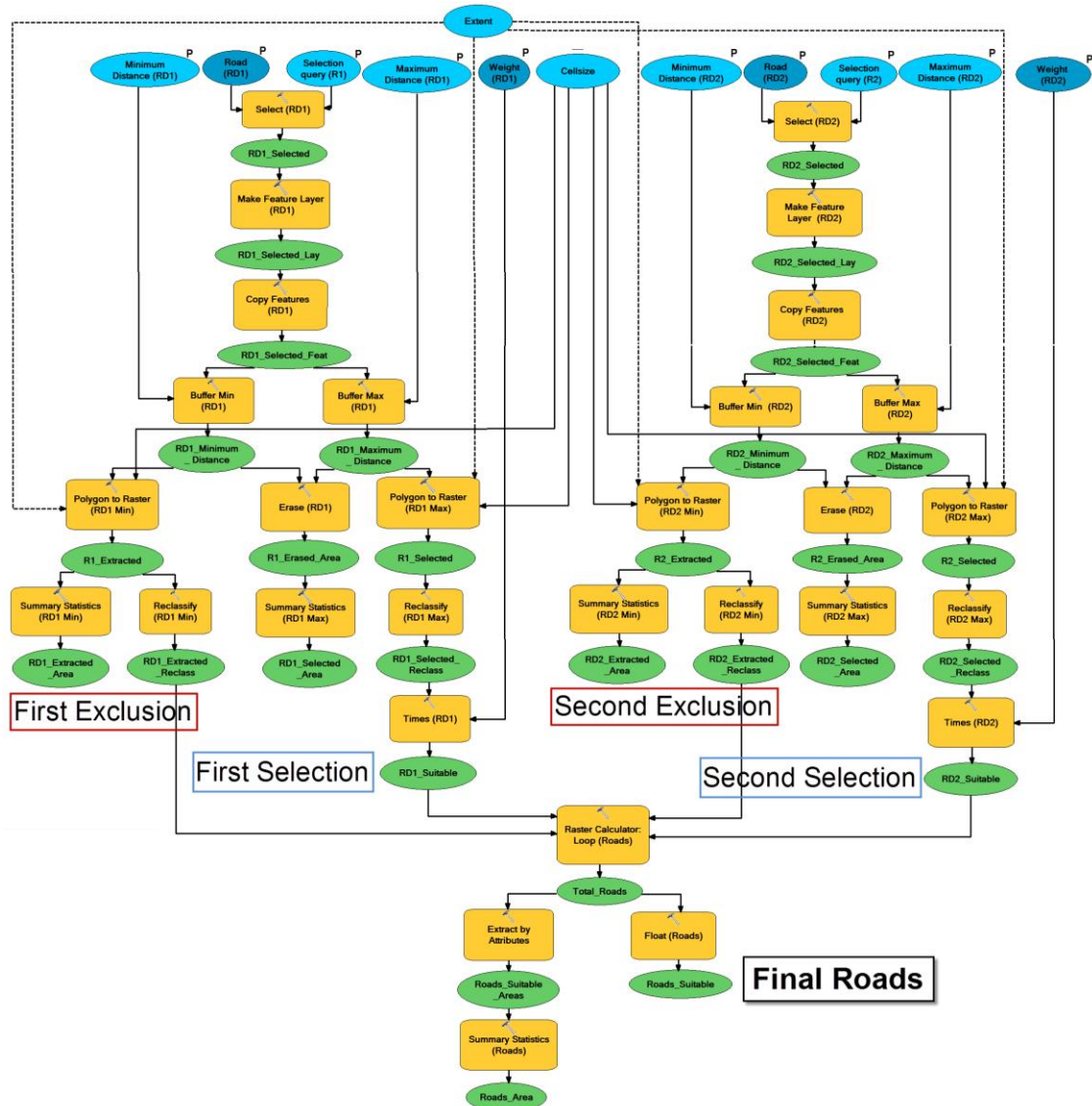


Figure 66: Roads in model 2. This model processes two vectors, which generate four different outputs. Two rasters contain areas to erase and two rasters contain selected roads with assigned weights. Afterwards, these outputs are combined in a raster of suitable roads with final weights. Figures 67 and 68 represent a zoom in of this model.

The raster processing extend has also been defined with the output of Wind resources model, creating a variable of “Extend” which is connected to the corresponding tools. Each input vector will be processed as followed:

- 1) **Select by attributes:** An attribute query introduced by the users select suitable roads according to their characteristics, such as width and state of their pavement or regular volume of traffic.
- 2) **Make feature layer.**
- 3) **Copy features.**
- 4) **Buffer of minimum distance (Full, Round, All):** Because of the legislation or project’s preferences, a minimum distance must be kept from the selected roads. “Buffer” generates and dissolves the polygons according to a distance introduced by users, which will be used to erase roads and their surroundings.
- 5) **Polygon to raster:** The output vector from “Buffer” needs to be transformed to raster in order to apply rest of the tools, obtaining the same cell size as the output of Wind resources model.
- 6) **Reclassify:** While areas outside buffered areas are assigned value 0 not having any effect during the rest of geoprocessing, all the cells inside buffered areas are reclassified as NoData to be erased from the final suitable areas when adding rasters in the “Raster calculator”.
- 7) **Summary statistics:** Used to indicate the users the erased area.
- 8) **Buffer of maximum distance (Full, Round, All):** A second buffer around the selected roads is generated in order to increase the suitability of those areas that are close enough to a selected transportation network.
- 9) **Erase:** Its output is a polygon representing the area between the two buffers (between the maximum and minimum distances), which will acquire a weight introduced by the users and will be used to calculate how much area is considered as suitable with “Summary Statistics”.
- 10) **Summary Statistics.**
- 11) **Polygon to raster:** The output of “Erase” also needs to be transformed to raster.
- 12) **Reclassify:** On the one hand, the suitable areas are assigned value 1 which will get an inserted weight when the tool “Times” multiplies the raster by the weight. On the other hand, areas further than the considered maximum distance contain NoData after “Polygon to raster” tool. They must be reclassified to 0, because although distant areas might reduce severely project’s budgets, turbines can still be built. Ergo they should not be erased.
- 13) **Times:** Applied to assign the weight to cells with value 1 (suitable).

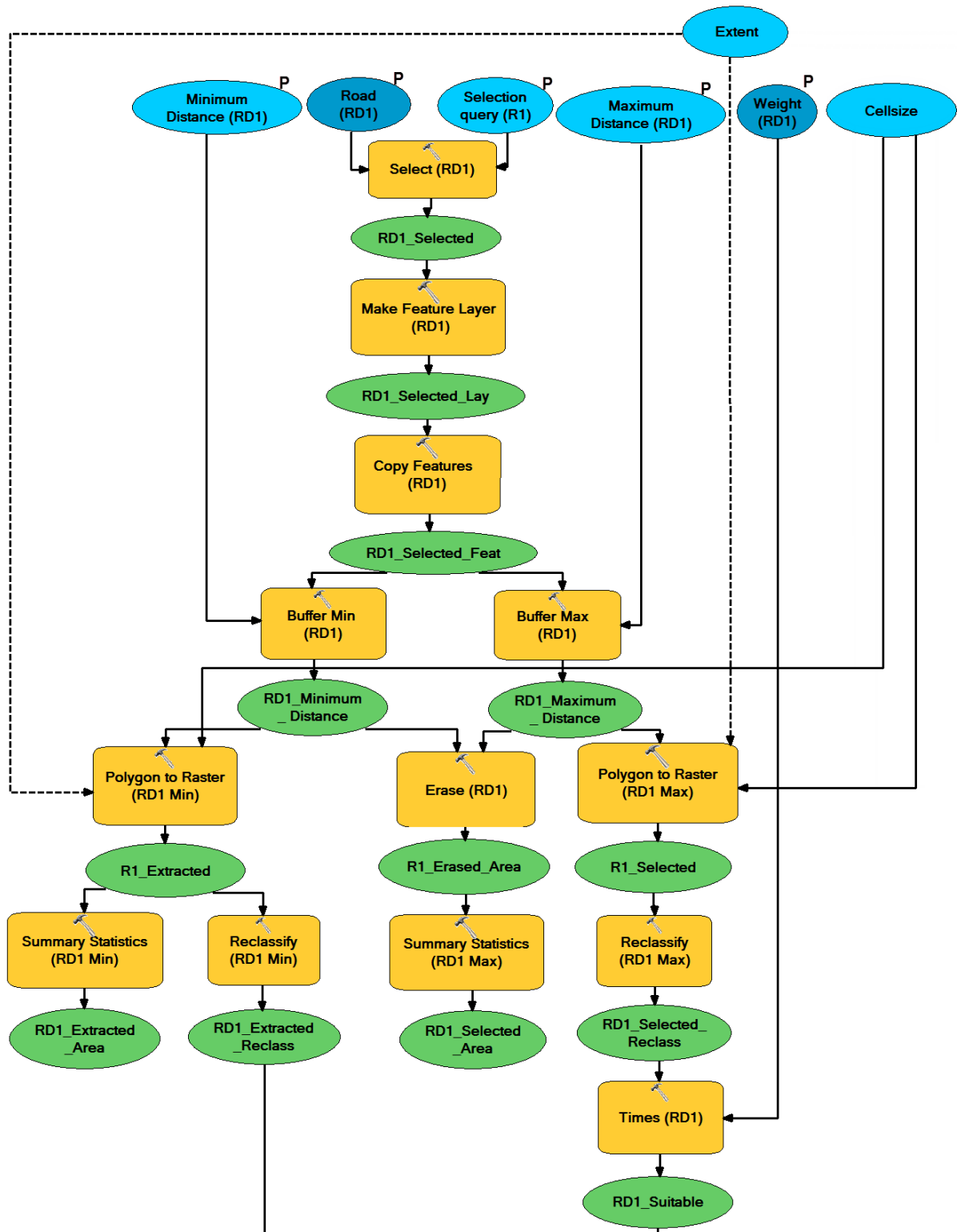


Figure 67: First selection of Roads in model 2. Geoprocessing applied to each vector input.

The rasters containing suitable areas and areas to exclude are added in “Raster Calculator”:

1. **Raster Calculator:** While all the cells containing NoData are automatically erased when combining all the rasters, rest of cells add their weights according to location, showing the final grade of suitability for Roads’ submodel.
2. **Float:** The previous output is transformed to floating-point generating the final output of this submodel.
3. **Extract by attributes and Summary Statistics:** An extraction of cells with value greater than 0 is applied to the output of “Raster calculator” in order to count the suitable cells with “Summary Statistics”.

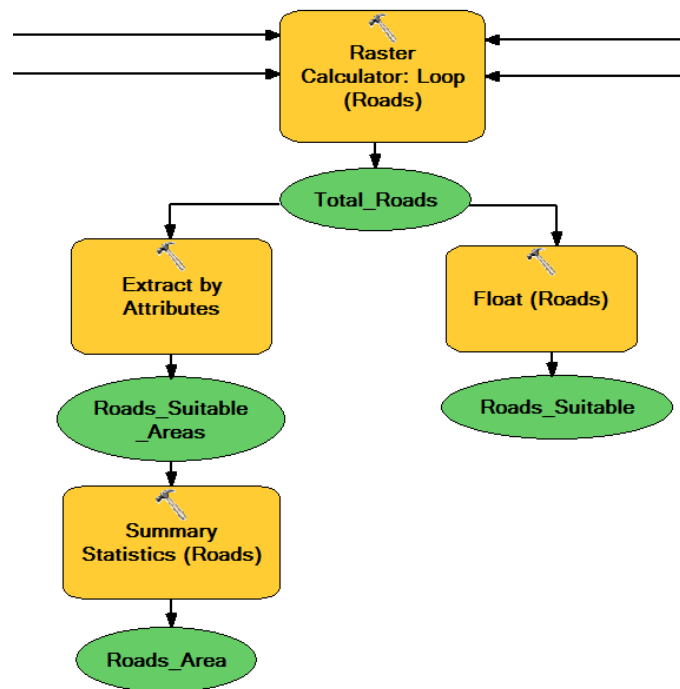


Figure 68: Total selected roads calculation of model 2.

Model 3 (from figure 69 to 72): As in model 2, also the selected roads and their surroundings are erased. The difference relies on a fuzzy distribution of weights within suitable areas, where the further a cell is from selected roads, the smallest is its weight. This reflects the fact that when a wind farm is installed far away from existing transportation networks, additional roads need to be built for the machinery required to transport, assemble and maintain its turbines.

Again, the next sketch is given to obtain a general idea of the workflow although it is difficult to read, but two zooms in can be found in figures 71 and 72.

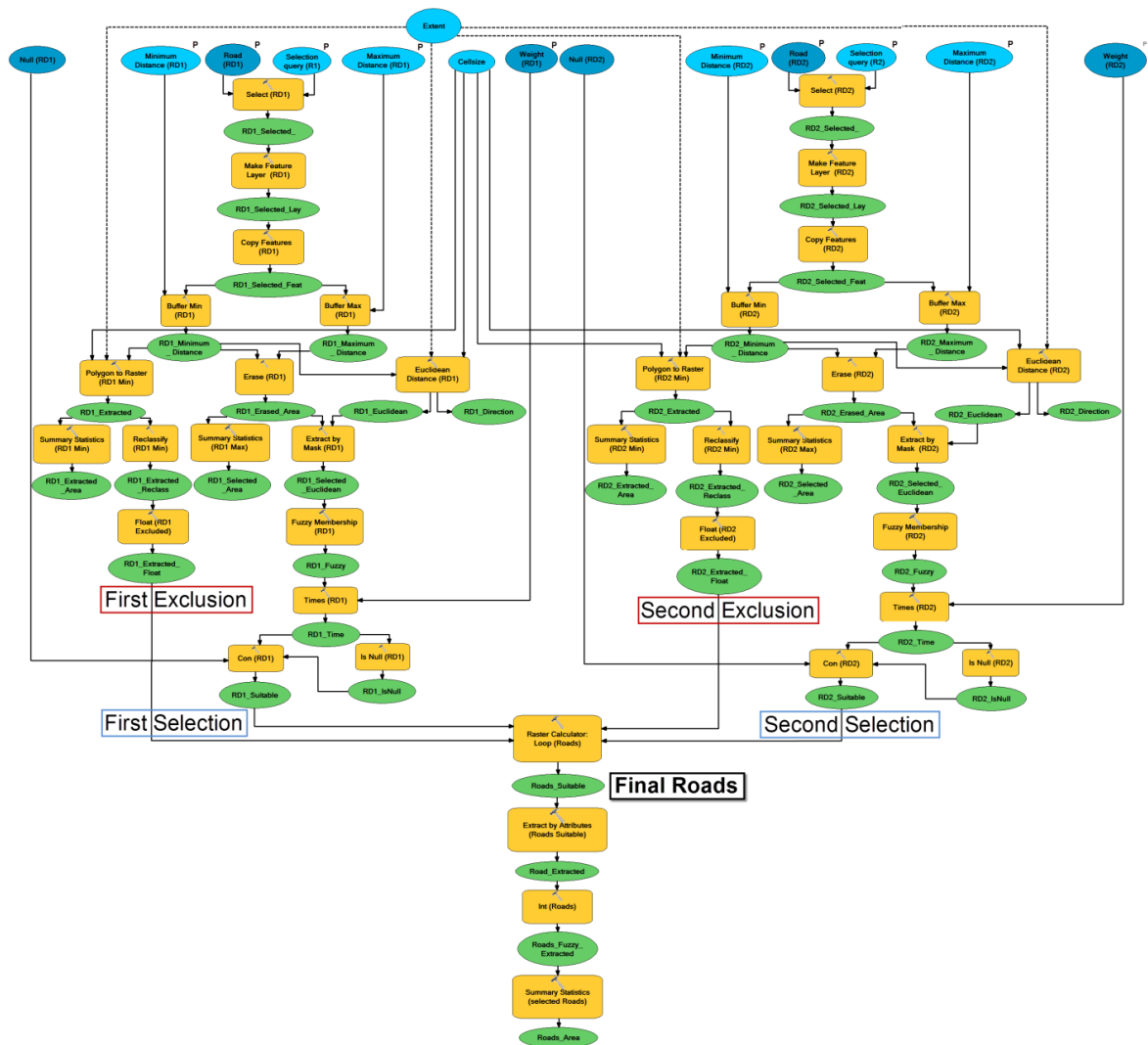


Figure 69: Roads in model 3. This model processes two vectors, which generate four different outputs. Two Raster containing areas to erase and two raster containing selected roads with weights assigned with a fuzzy membership. Afterwards, these outputs are combined in a raster representing suitable roads with final weights. Figure 71 and 72 represent a zoom in of this model.

First steps are the same as in model 2: **Select by attributes, Make feature layer, Copy features, Buffer of minimum distance, Polygon to raster, Summary statistics and Reclassify.** Afterwards:

- 1) **Float:** While in model 2 inputs of “Raster calculator” are integer rasters and the output is transformed to floating-point raster, in this model “Fuzzy membership” generates already outputs as floating-point rasters. Therefore, outputs from “Reclassify” are processed with “Float”, not needing to use this tool after “Raster calculator”.
- 2) **Buffer of maximum distance (Full, Round, All):** As model 2.
- 3) **Erase and Summary Statistics:** As model 2.
- 4) **Euclidean distance:** Applied to generate a raster where each cell indicates how far it is from the selected roads and their surroundings.

- 5) **Extract by mask:** The selected suitable area (output from “Erase”) is then exacted from the output of “Euclidean distance” since it is the area which needs to be analyzed (see figure 70). Remaining area contains NoData cells.
- 6) **Fuzzy membership (linear with negative slope):** A negative slope linear transformation reclassifies the distances to a 0 to 1 scale. In this case, the tool is configured so that the minimum is greater than the maximum in order to generate a negative relationship. This way, any value above the maximum distance is assigned value 0, which increases proportionally to the distance until 1, creating an area of maximum suitability at the border of erased areas (roads and surroundings) (see figure 70).
- 7) **Times:** Assigns the weight inserted by users respecting the fuzzy distribution (see figure 70).
- 8) **Is Null:** Although areas outside the extracted mask are not especially appropriate because of their distance, wind farms might be still profitable. Therefore, their NoData cells must be transformed to 0 so that they are not erased when applying “Raster Calculator”. “Is Null” detects these cells and assign them value 1 (see figure 70).
- 9) **Con:** Transforms NoData cells to 0, maintaining rest of cells with the original values in the output of “Times” which will generate the output RD1_suitable (see figure 70).

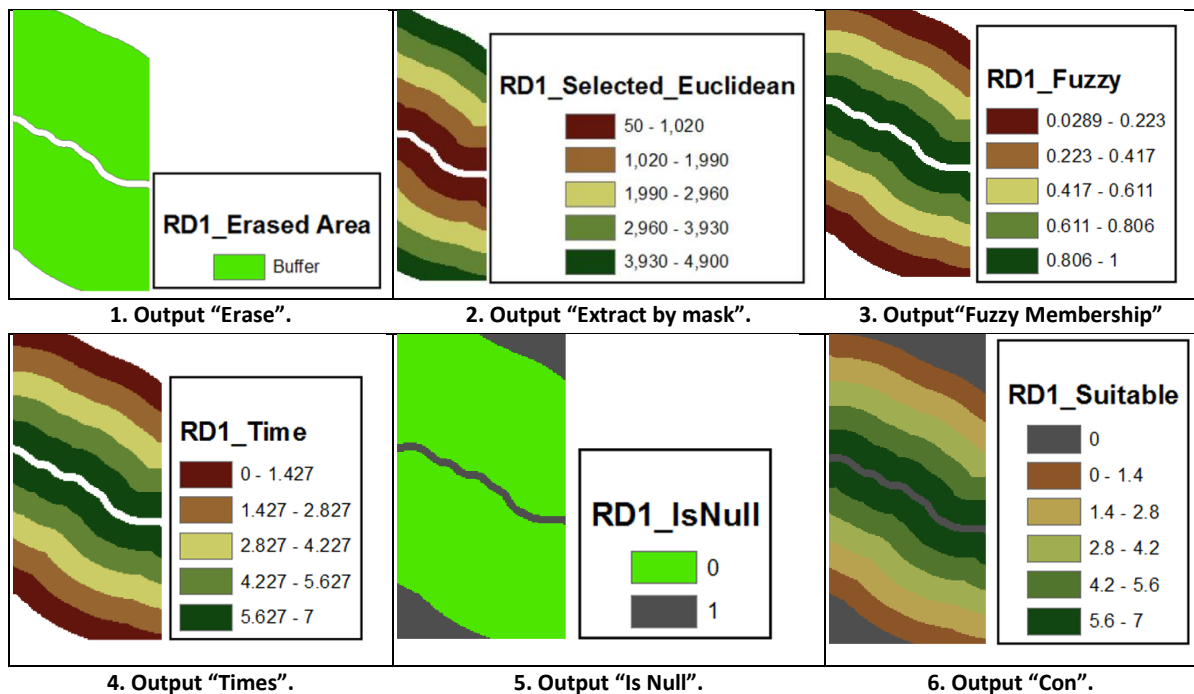


Figure 70: Intermediate outputs of Roads in model 3. “Erase” generates a vector (1) containing the area between the two buffers which will acquire the weight of suitability. This area is used to extract the values from the output of “Euclidean Distance”, generating a raster (2) of distances from excluded areas. This raster is processed with “Fuzzy membership”, obtaining a raster (3) where 1 corresponds to the closest distance decreasing until 0. This raster is multiplied by the weight with the tool “Times” (4). Afterwards, NoData (value 1 in raster 5) must be identified and reclassified as 0 (in raster 6), obtaining a raster of suitable roads.

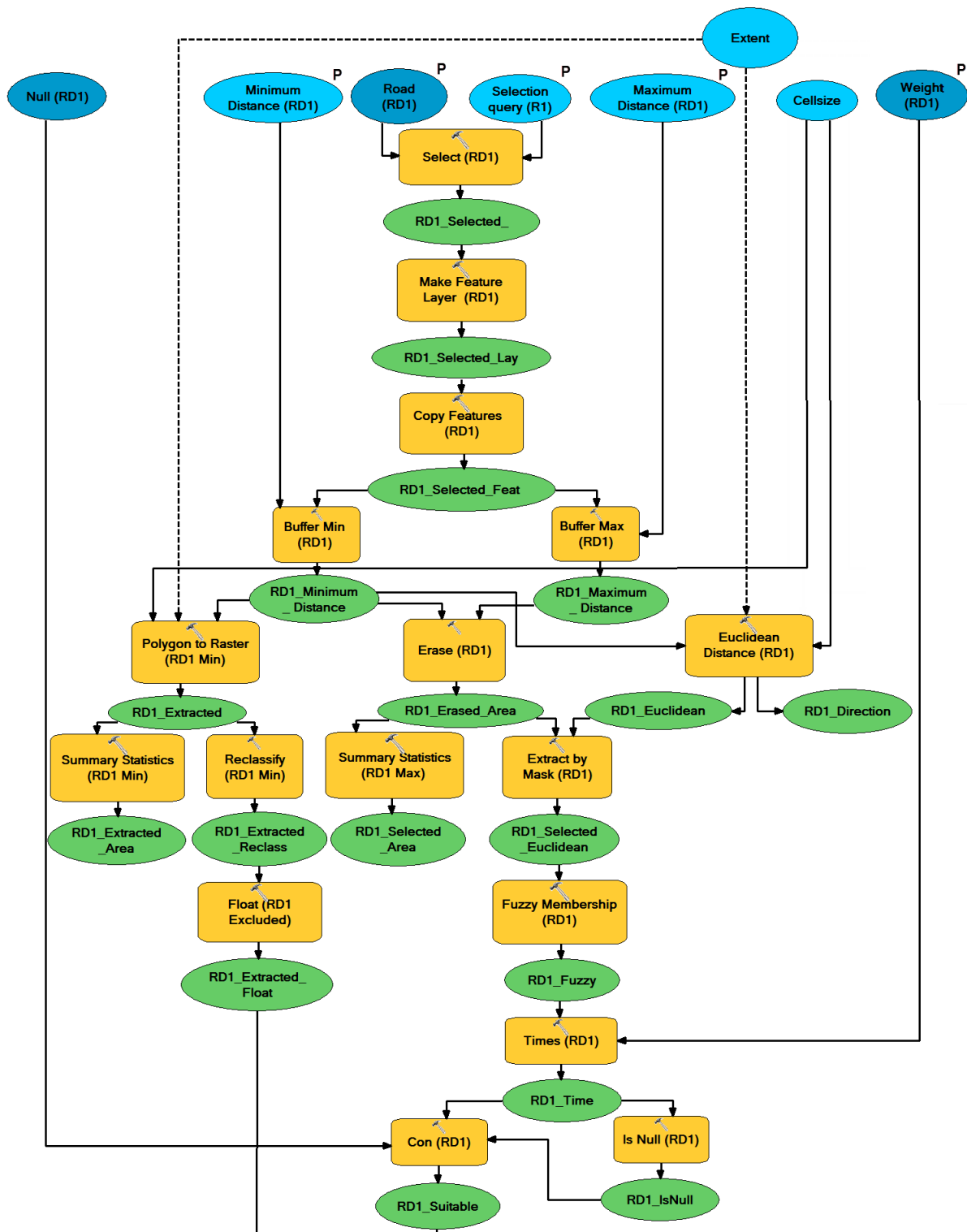


Figure 71: First selection of Roads in model 3. Geoprocessing applied to each vector input.

Afterwards, the two selections and exclusions are added in “**Raster calculator**” generating the final output of model 3. In order to indicate users how much area is considered as suitable, this raster is then processed with **Extract by attributes** (to extract only cells with values greater than 0), **Int** (to obtain a VAT table) and Summary Statistics (to count cells). See figure 72.

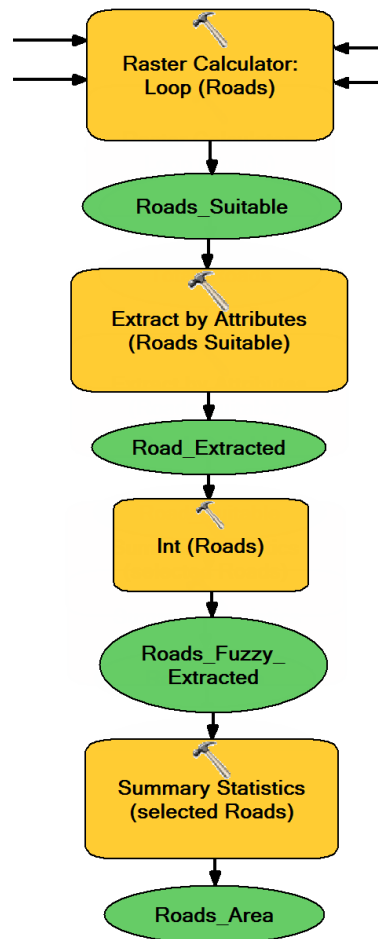


Figure 72: Calculation of final Roads in model 3.

4 Power lines

Estimation about how much power a wind park generates is required in order to select an appropriate connection to the existing power lines. Besides, proximity to these lines reduces costs of installation of new cables between the wind turbines and the grid connection points. This criterion is not considered by **model 1**.

Model 2 (figure 73): First an attribute query selects the power lines capable of receiving the electrical power generated by a concrete wind park. Afterwards, a buffer is created around the appropriate lines, assigning full weight to those areas within an indicated distance.

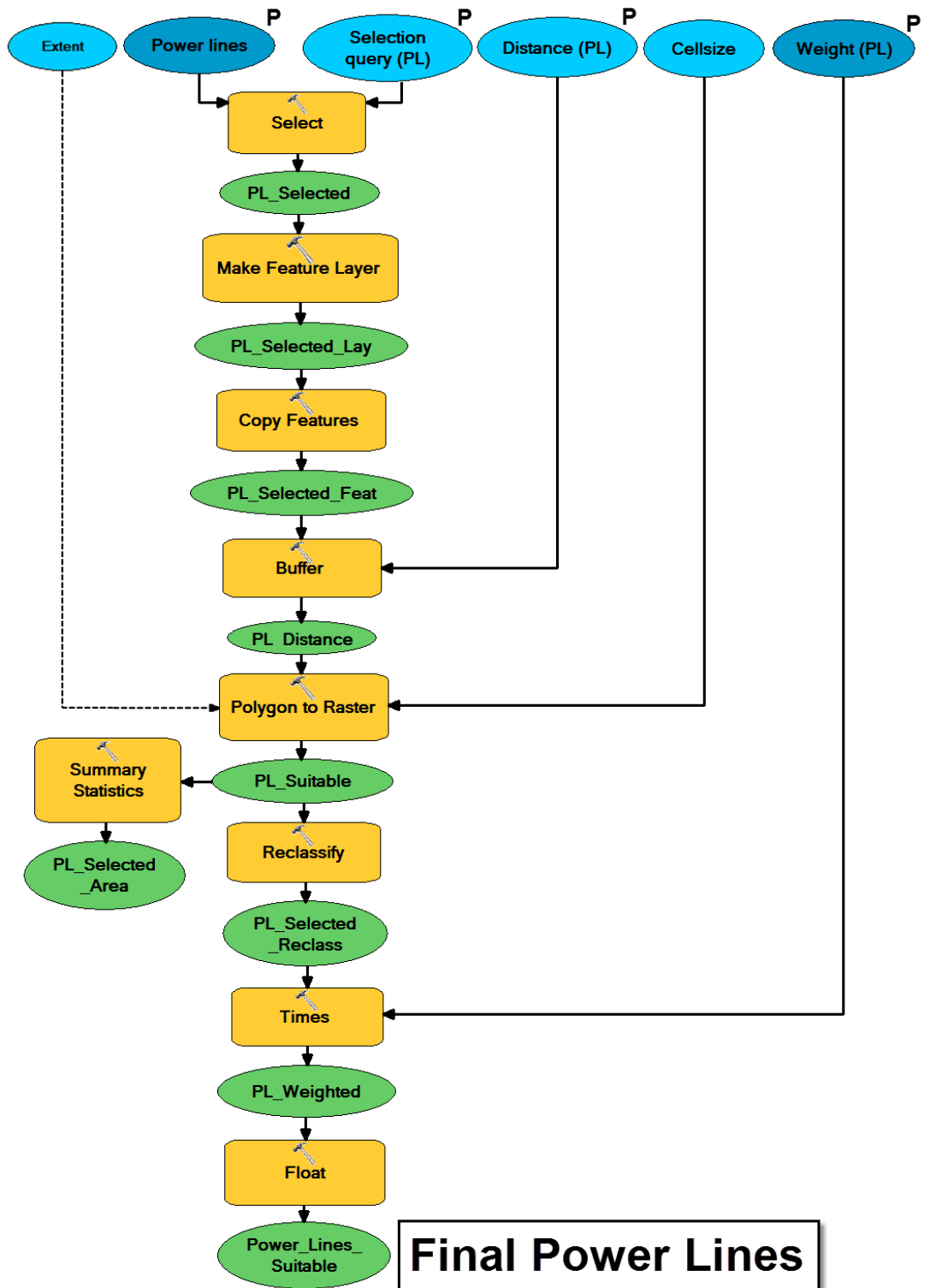


Figure 73: Power lines in model 2. This model processes a vector and generates a raster with areas close to the suitable power lines.

An input vector containing the power lines will be processed as follows:

- 1) **Select by attributes:** Applied to select the appropriate power lines by an attribute query.
- 2) **Make feature layer.**
- 3) **Copy features.**
- 4) **Buffer (Full, Round, All):** Used to generate a polygon representing all the areas close enough to selected lines.
- 5) **Polygon to raster:** The previous output vector is transformed to raster obtaining the cell size from the output of wind resources.
- 6) **Summary statistics:** Calculates the area which will carry a weight of suitability.
- 7) **Reclassify:** Selected powers lines and nearby areas are reclassified as 1 so that they acquire the weight when “Times” is applied. Remaining cells obtain value 0, not being erased from final suitable areas since project’s budget might include the installation of a new electrical network.
- 8) **Times:** Cells with 1 obtain full weight adding this grade of suitability in the final sitting.
- 9) **Float.**

Model 3 (figure 74): Fuzzy distribution of weights generates an output raster where the further the cell is from selected power lines, the smaller is its weight, and vice versa.

- 1) **Select by attributes:** As model 2.
- 2) **Make feature layer:** As model 2.
- 3) **Copy features:** As model 2.
- 4) **Euclidean distance:** Applied to obtain a raster indicating how far away each cell is from the closest selected power line.
- 5) **Buffer (Full, Round, All):** As model 2.
- 6) **Extract by mask:** Cells in the output from “Euclidean distance” which matches up the buffer are extracted to a new raster in order to distribute the weights proportionally to the distance.
- 7) **Fuzzy membership (linear with negative slope):** Borders of buffered area obtain 0 while rests of cells increase their value until 1 in the selected power lines.
- 8) **Times:** Multiplying the pervious raster by the inserted weight generates a raster where the closest cells contain full weight, decreasing to 0 in the borders of the buffered area.
- 9) **Int and Summary Statistics:** Since “Euclidean distance” generates a floating-point raster, “Int” must be used in order to generate a VAT table where “Summary Statistics” can count the selected cells.

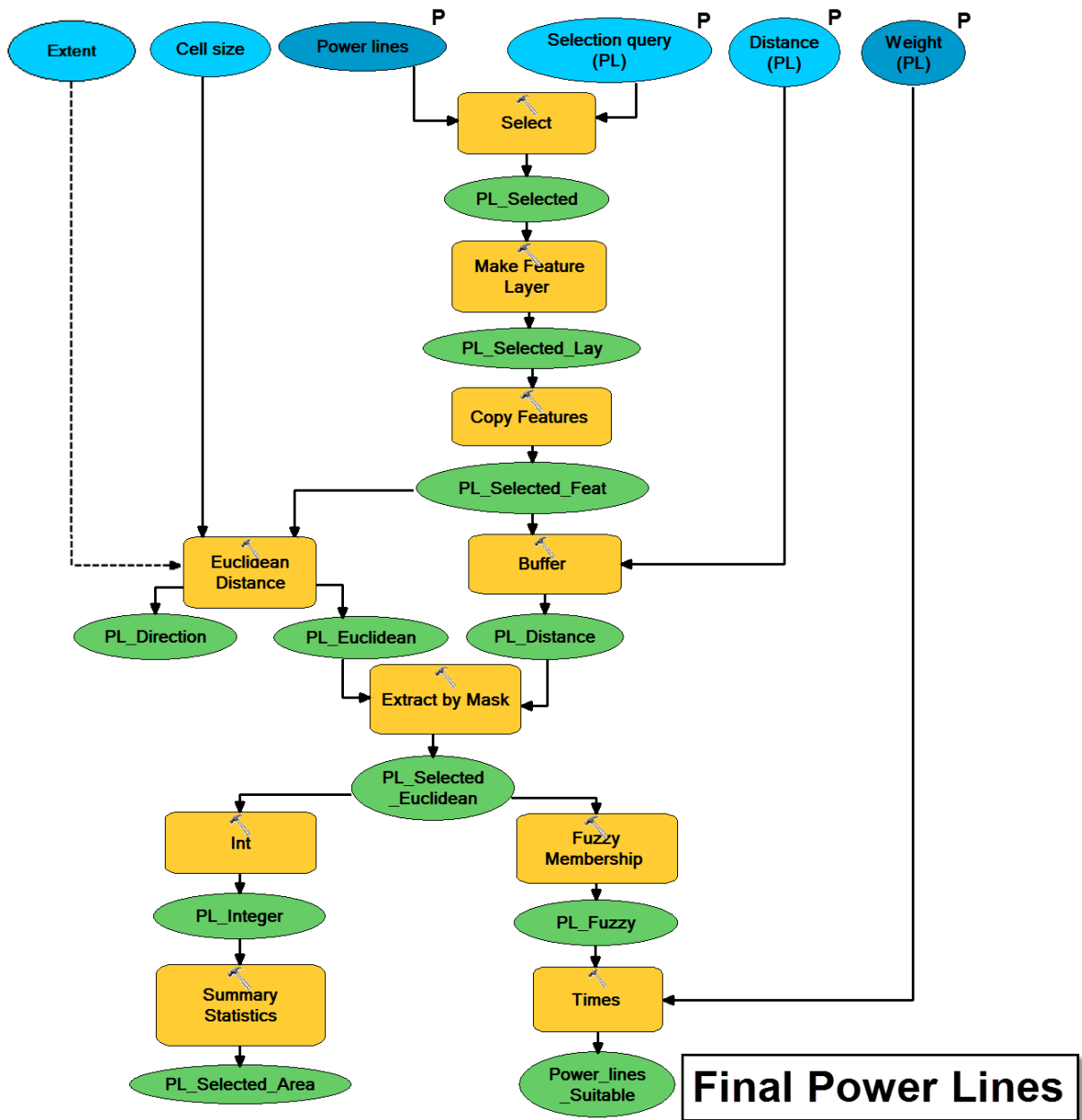


Figure 74: Power lines in model 3. This model processes a vector and generates an output raster with areas close to suitable power lines, where closest cells contain the highest weight.

5 Railways

Wind parks should not be built within a minimum distance from railways because of security reasons. Besides, a considerable distance minimizes visual impact. This criterion is not considered in **model 1**.

Model 2 (figure 75): Railways and their surroundings are buffered within a minimum distance selected by users and erased from the final suitable areas. The remaining areas carry the same weight of suitability.

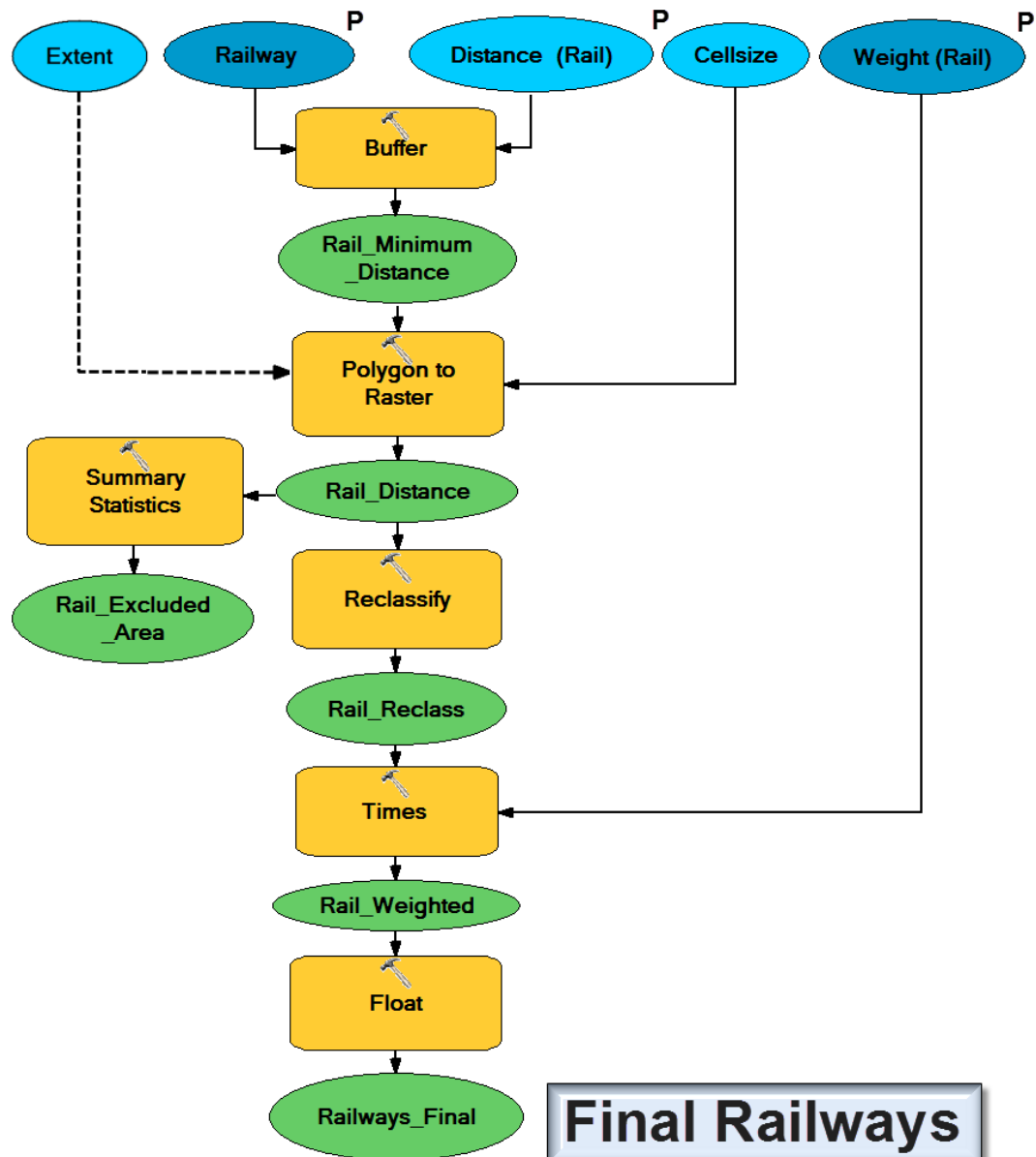


Figure 75: Railways in model 2. This model processes a vector, generating a raster containing areas to exclude and areas which will carry the inserted weight in the final selection.

Workflow:

- 1) **Buffer (Full, Round, All):** A buffer is generated around all the features (railways) of the input according to an inserted distance.
- 2) **Polygon to raster:** Transforms the buffered area into a raster.
- 3) **Summary statistics:** Indicates to the users the area of railways and surroundings which will be erased.
- 4) **Reclassify:** As in previous models, while cells in the buffer are transformed to NoData in order to erase them in further calculations, the rest of cells are reclassified with value 1 representing suitable areas.
- 5) **Times:** Provides a weight to the suitable areas.
- 6) **Float.**

Model 3 (figure 76): In contrast to model 2, the influence of the distance on the visual impact is included. Once a safety distance is guaranteed, it should be considered that the further the wind farm is from rails, the less visual impact is generated in the landscape. Workflow:

- 1) **Buffer:** As model 2.
- 2) **Polygon to raster:** As model 2.
- 3) **Summary statistics:** As model 2.
- 4) **Reclassify:** While in this model also the buffered cells are transformed to NoData in order to be erased, the remaining areas are now reclassified as 0 (instead of 1) in order not to have any effect when adding the two output rasters in the "Raster calculator".
- 5) **Float:** It generated the floating-point raster containing the areas to exclude for safety reasons.
- 6) **Euclidean distance:** Distance is calculated directly from the buffered areas and not from railways. The first reason is that if the distance was calculated from rails, the full weight would be assigned at the border of rails and railways' full weight would disappear from the suitable areas when adding the raster containing areas to exclude, although a proportional distribution of weights would have been kept. Besides, there is no need of unnecessary geoprocessing.
- 7) **Fuzzy membership (linear with positive slope):** The further the cells are from buffered areas, the closer its value is to 1, representing a minimization of visual impact with the distance.
- 8) **Times:** Provides a weight to suitable areas.
- 9) **Raster calculator:** Addition of both rasters generates the output floating-point raster of Railways model.

A sketch of this model is given in next figure.

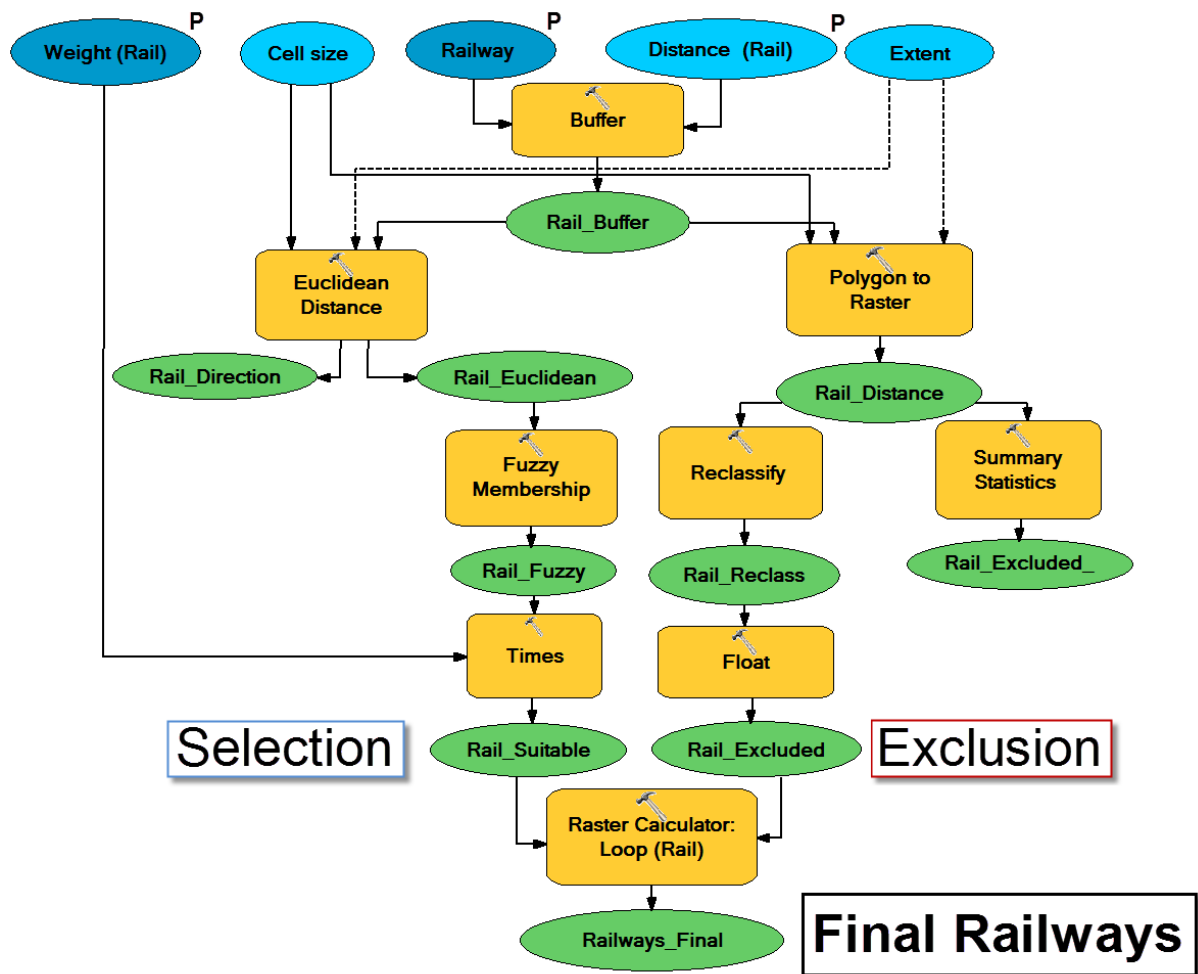


Figure 76: Railways in model 3. This model processes a vector, generating a raster containing areas to exclude and areas which will carry the inserted weight relatively to its distance.

6 Land Use

Wind farms should be compatible with the existing land uses and depending on the characteristics of a project, legislation forces to maintain a certain distance in order to avoid visual impact, noise or because of safety reasons.

Model 1 (figure 77): This model considers a minimum distance from settlements (Ortslage) which are erased from the suitable areas. Workflow:

- 1) **Buffer (Full, Round, All):** Generates a buffer around the input vector of settlements which will be erased from the final areas.
- 2) **Summary statistics:** Calculates the buffered area.

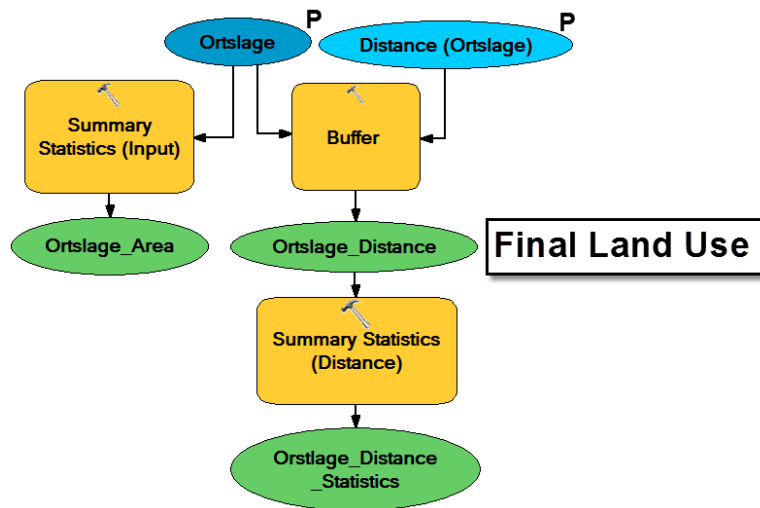


Figure 77: Land Use in model 1. A minimum distance is guarantee by generating a buffer around selected urban areas, which will be erased from final site selection. It has been designed according to the specifications of LUBW

Model 2 (from figure 78 to 80): This model allows two different spatial analyses. On the one hand, four vectors can be processed excluding the selected land uses and their surroundings while given a suitability weight for the remaining areas. For example, it would be an appropriate analysis for urban, mixed and industrial areas since they must be excluded by law. On the other hand, two vectors can be processed by selecting land uses for which suitability wants to be increased. For example, a wind farm located on pasture areas is compatible with stockbreeding. A general view over the workflow can be obtained in next figure. Figure 79 and 80 represent two zooms in.

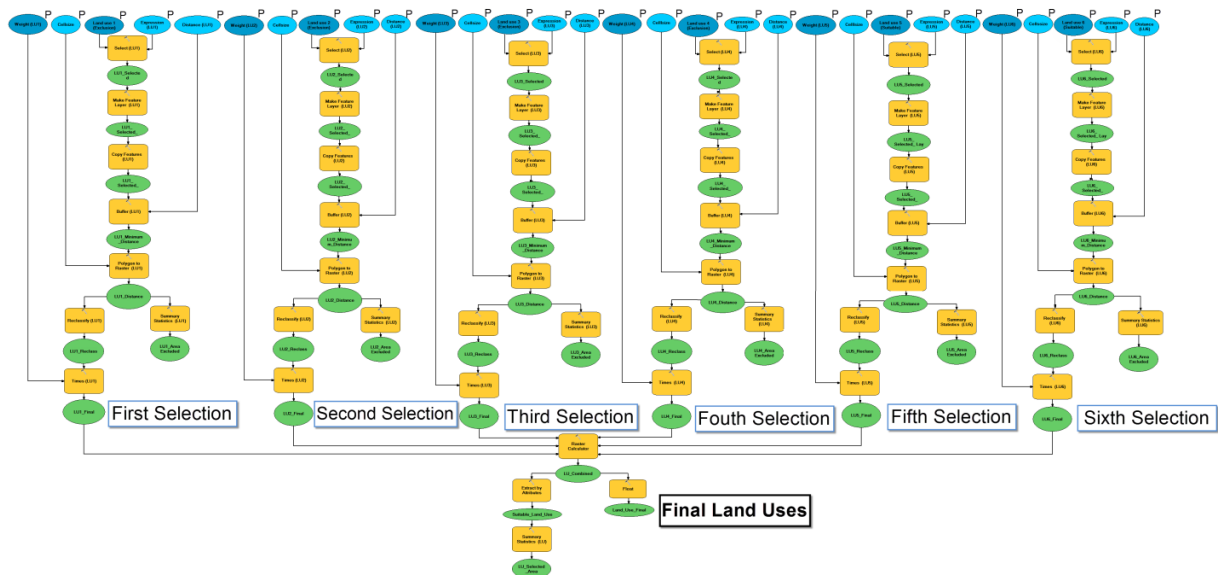


Figure 78: Land Use in model 2. Land uses are selected and buffered in the six input vectors according to an inserted distance. First 4 buffers are erased from final site selection assigning the weight to remaining areas. Second 2 buffers are designed only to increase suitability in these areas.

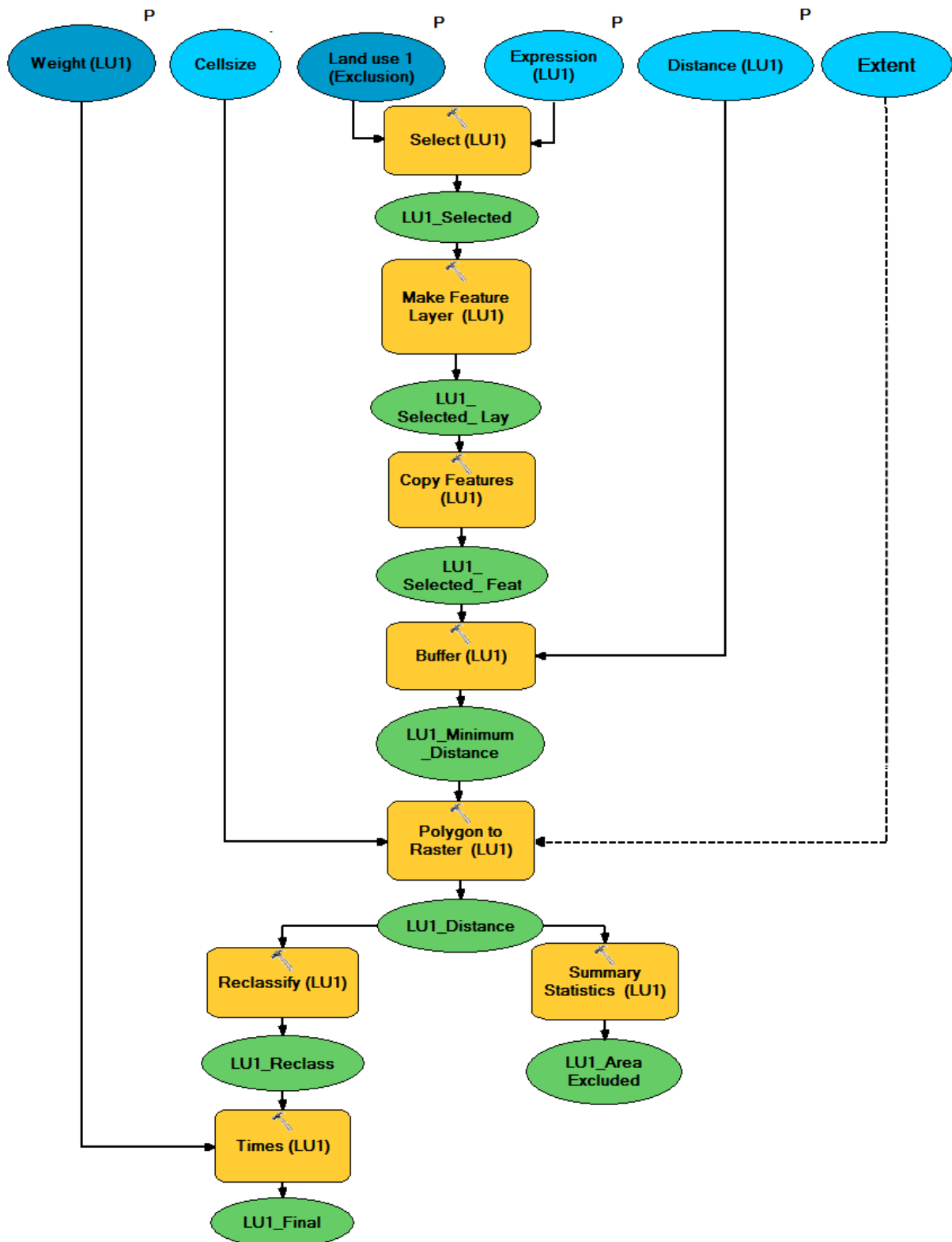


Figure 79: First selection of Land Use in model 2. Geoprocessing applied to each vector input.

Workflow:

- 1) **Select by attributes:** User selects concrete land uses based on an attribute query.
- 2) **Make feature layer and Copy features.**
- 3) **Buffer (Full, Round, All) and Polygon to raster:** An area around the selected land uses is generated according to a minimum distance introduced by users. Then, the output vector is transformed to raster obtaining the cell size from the output of wind resources' submodel 2.
- 4) **Summary statistics:** Calculates the buffered area.
- 5) **Reclassify and Times:** Two different reclassifications are performed depending on the input. The first one is applied to the first four selections, for which all the cells inside the polygon areas are reclassified as NoData in order to be erased from the final suitable locations. The remaining cells are transformed to 1 so that they acquire a weight when "Times" is applied. The second one is applied to the two last selections, where cells inside polygons are reclassified as 1 in order to obtain the assigned weight and increase the suitability when combining land uses. The remaining cells are reclassified as 0 since they must not be erased.

The output raster does not need to be converted to floating-point since all the outputs would be combined in the "Raster Calculator" tool as integer and then transformed to "Float", preparing the output raster for the final selection. "Extract by attributes" extract all the cells with value greater than 0 in order to calculate the final suitable area with "Summary statistics".

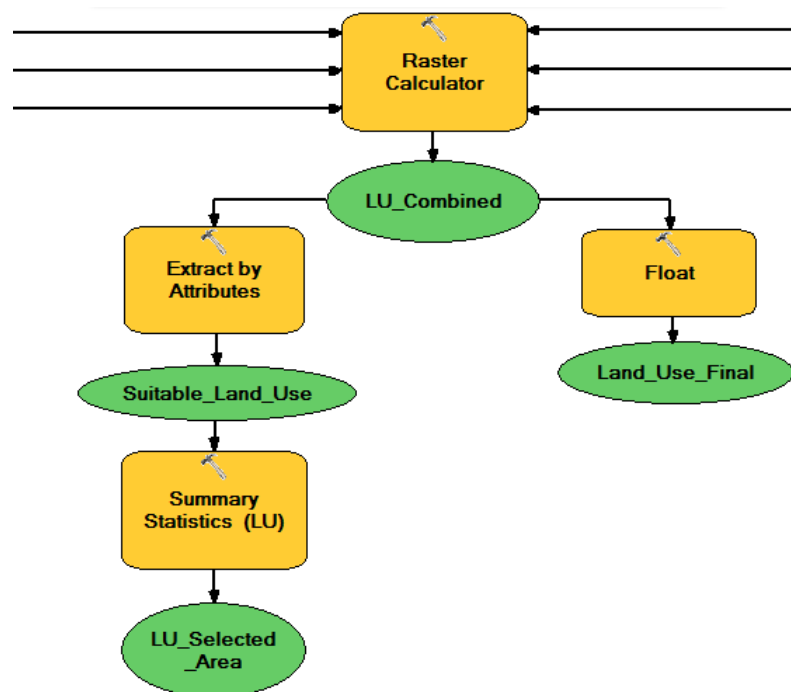


Figure 80: Calculation of final Land Use in model 2.

Model 3 (from figure 81 to 83): When a wind farm is not compatible with a land use, possible impacts are usually reduced with the distance. For example, although a minimum distance from urban areas is mandatory by law, the further the turbine, the less noise or visual impact is generated. Although the next sketch cannot be readable for its dimensions, it gives a general overview of flows in the geoprocessing. Please see figure 82 and 83 for a zoom in.

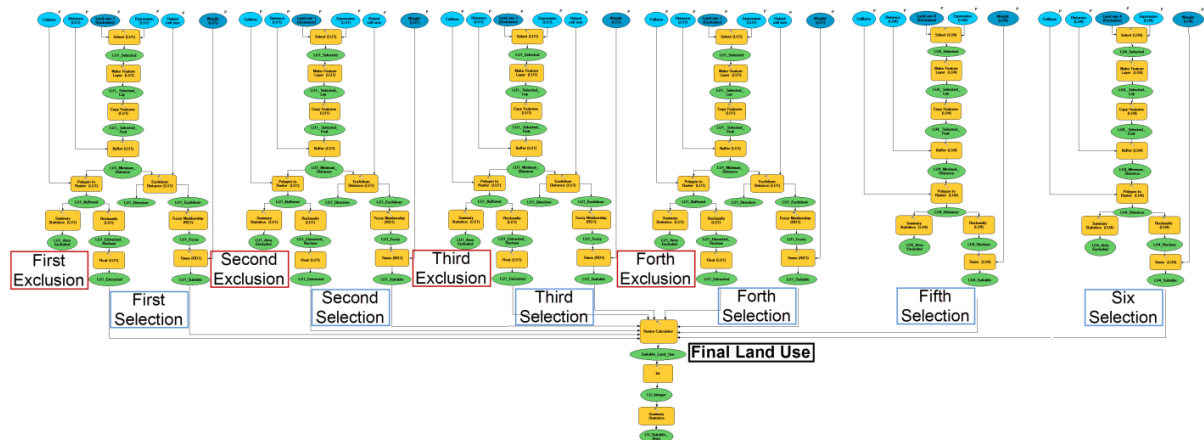


Figure 81: Land Use in model 3. Land uses are selected in the six vectors, generating a buffered area around them according to an inserted distance. While four of the buffers are erased from final site selection, assigning weight proportionally to distance within none buffered area; the other two only obtain a weight in the buffered area, increasing its suitability. Figures 82 and 79 represent a zoom in of this model.

First steps are the same than in model 2: **Select by attributes, Make feature layer, Copy features, Buffer, Polygon to raster** and **Summary statistics**. Afterwards:

- 1) **Reclassify:** Two different reclassifications are performed. The first one is applied to the first four selections in order to erase no compatible land uses and their surroundings. Consequently all the cells inside the buffer are reclassified as NoData while the remaining cells obtain value 0 in order not to have any effect when combining the output rasters. The second one is applied to the two last selections, where the cells inside the polygons are reclassified as 1 in order to obtained the weight and increase suitability in those area. The remaining cells are reclassified as 0 since they must not be erased.
- 2) **Float:** Reclassified rasters are integer and should be converted to floating-point.
- 3) **Euclidean distance (only for the first four selections):** Generates a raster from where to extract the distance to buffered areas.
- 4) **Fuzzy membership (linear positive slope):** The first four selections exclude non compatible land uses for which the possible negative impacts derived from turbines should decrease with the distance. Consequently, a linear transformation of the output from “Euclidean distance” is processed generating a raster where the closer a cell is to selected uses, the closer to 0 is its value; and the further the cell, the closer to 1. This is not applied to last two selections, where only an additional weight is given to compatible land uses.
- 5) **Times:** Assigns the weight.

The, these ten outputs are combined with the “Raster calculator” to generate the output floating-point raster of land use. As in previous models, “Extract by attributes”, “Int” and “Summary statistics” are applied to calculate the final suitable area.

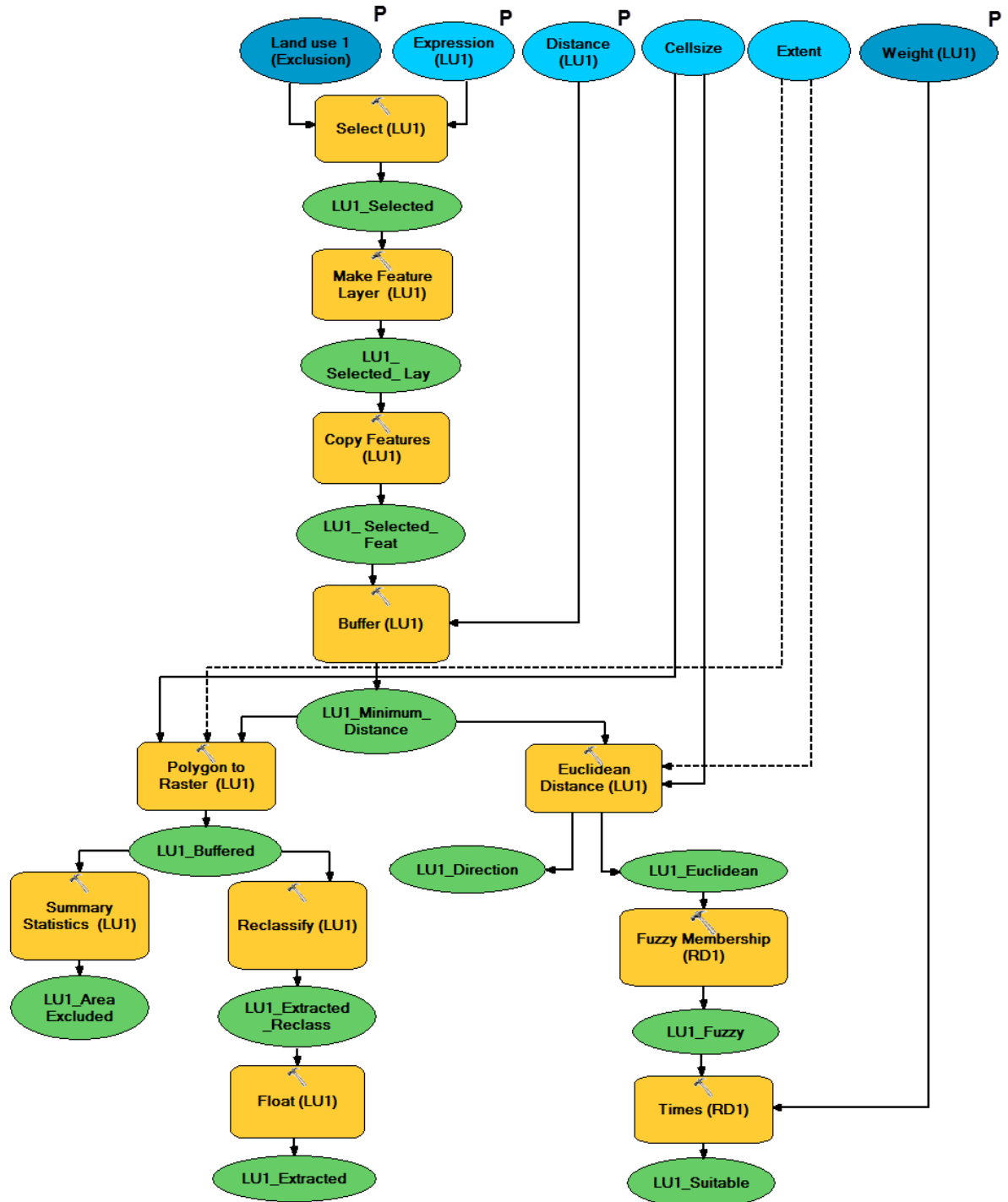


Figure 82: First selection of Land Use in model 3. Geoprocessing applied to the first four vector inputs.

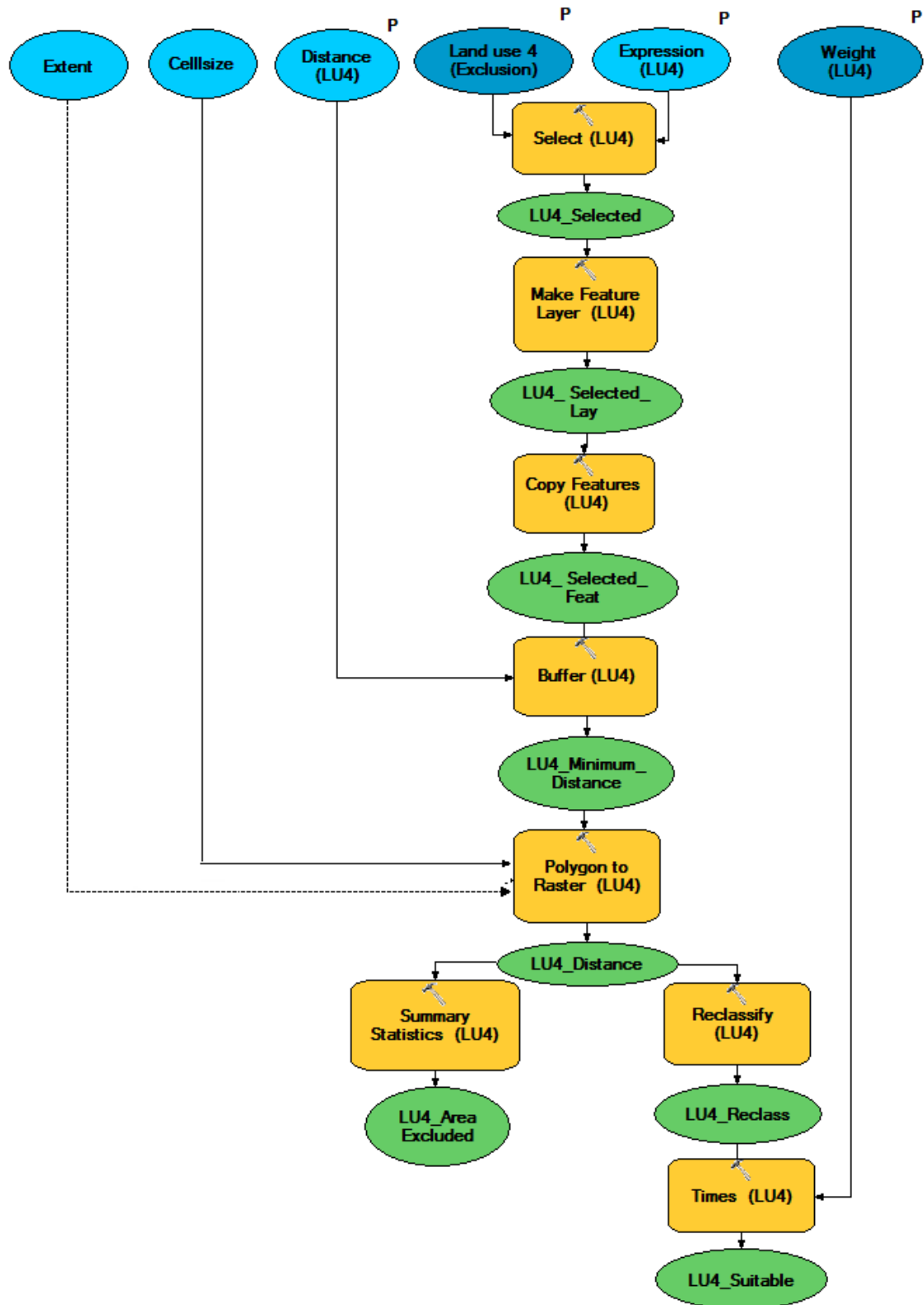


Figure 83: Fourth selection of Land Use in model 3. Geoprocessing applied to the last two vector inputs.

7 Water bodies

Some effects might be derived from large scale exploitations due to a slowdown in wind speeds which modify water temperature. Therefore, a minimum distance might be convenient to protect certain water bodies.

Model 1 (figure 84): water bodies are buffered following same spatial analysis than for land use.

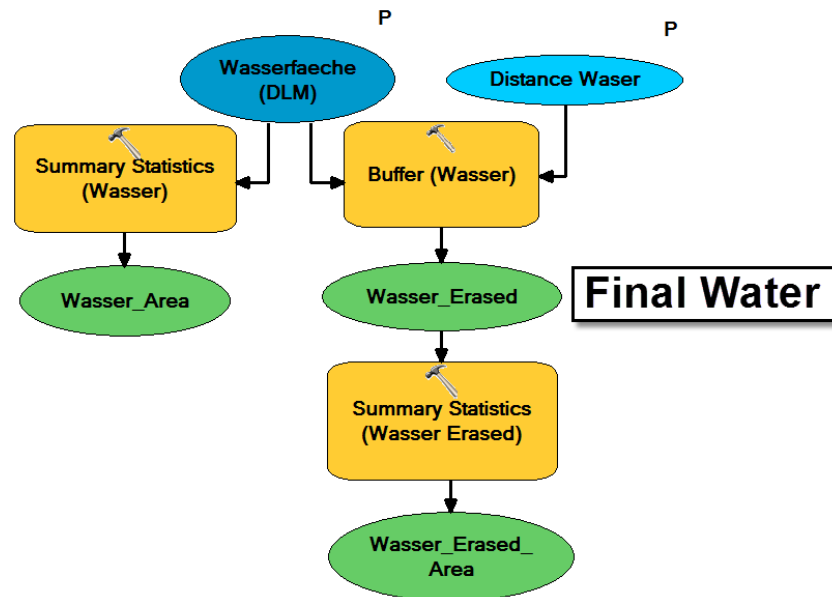


Figure 84: Water in model 1. A minimum distance is guarantee by generating a buffer around the input vector of water bodies, which will be erased from final site selection. It has been designed according to the specifications of LUBW

Model 2 (figure 85): This model allows user to process two different selections of water bodies. The reason is that on the one hand, some water bodies might have different figures of protection because of high vulnerability of their ecosystems; consequently a higher distance should be kept depending on the project. On the other hand, there are some policies that also include a distance to ground water (see section 9.1.2). The spatial analysis is the same as for the first selection of land use in model 2.

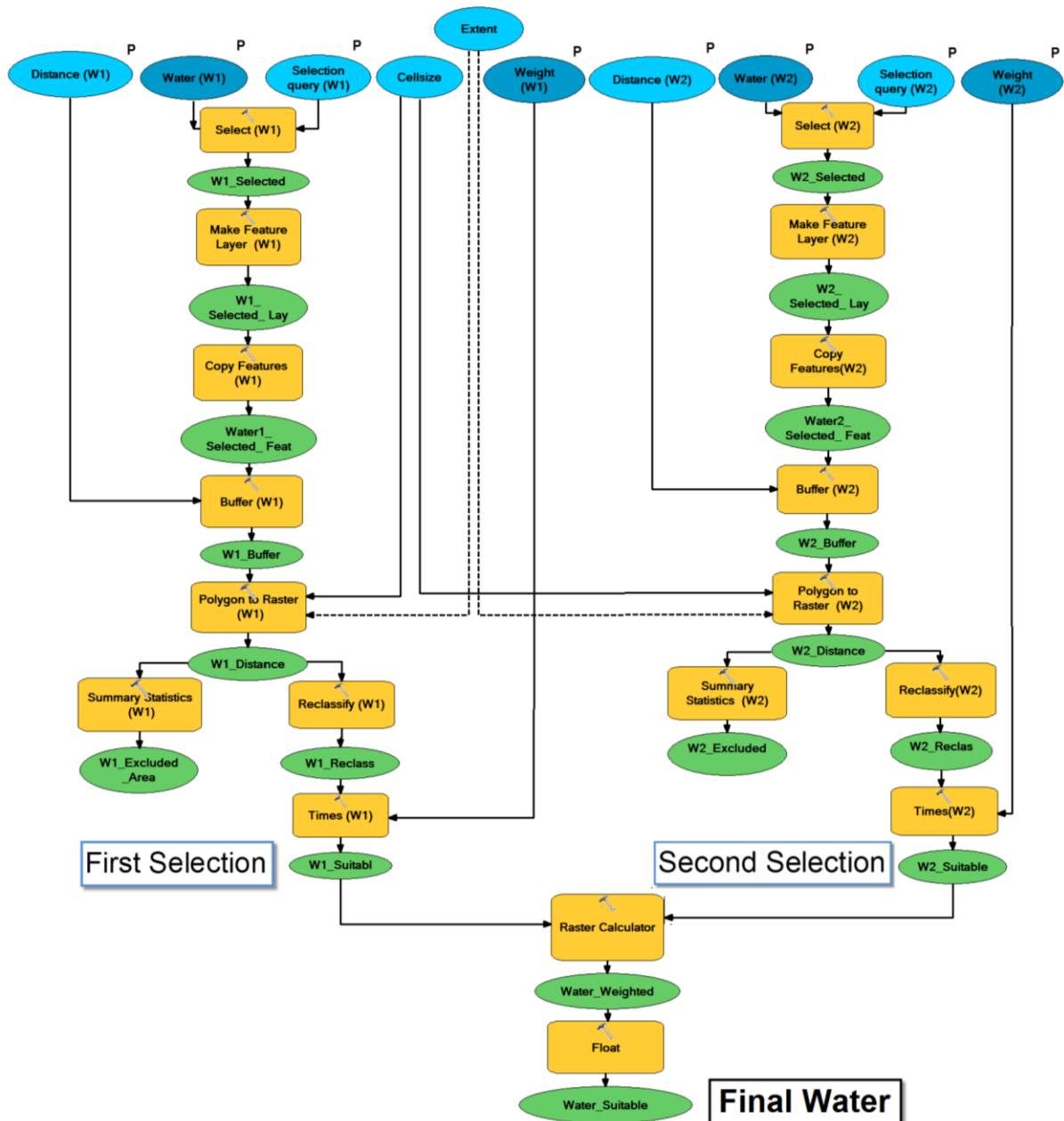


Figure 85: Water in model 2. Water bodies are selected from two input vectors, erasing then and their surroundings in the final site selection. Rest of areas is assigned a weight of suitability, indicating no impacts generated.

Model 3 (figure 86): The fuzzy membership applied in this model creates the relation where the further a water body is from a wind farm, the less it can be affected. Spatial analysis is the same as for the first selection of land use in model 3.

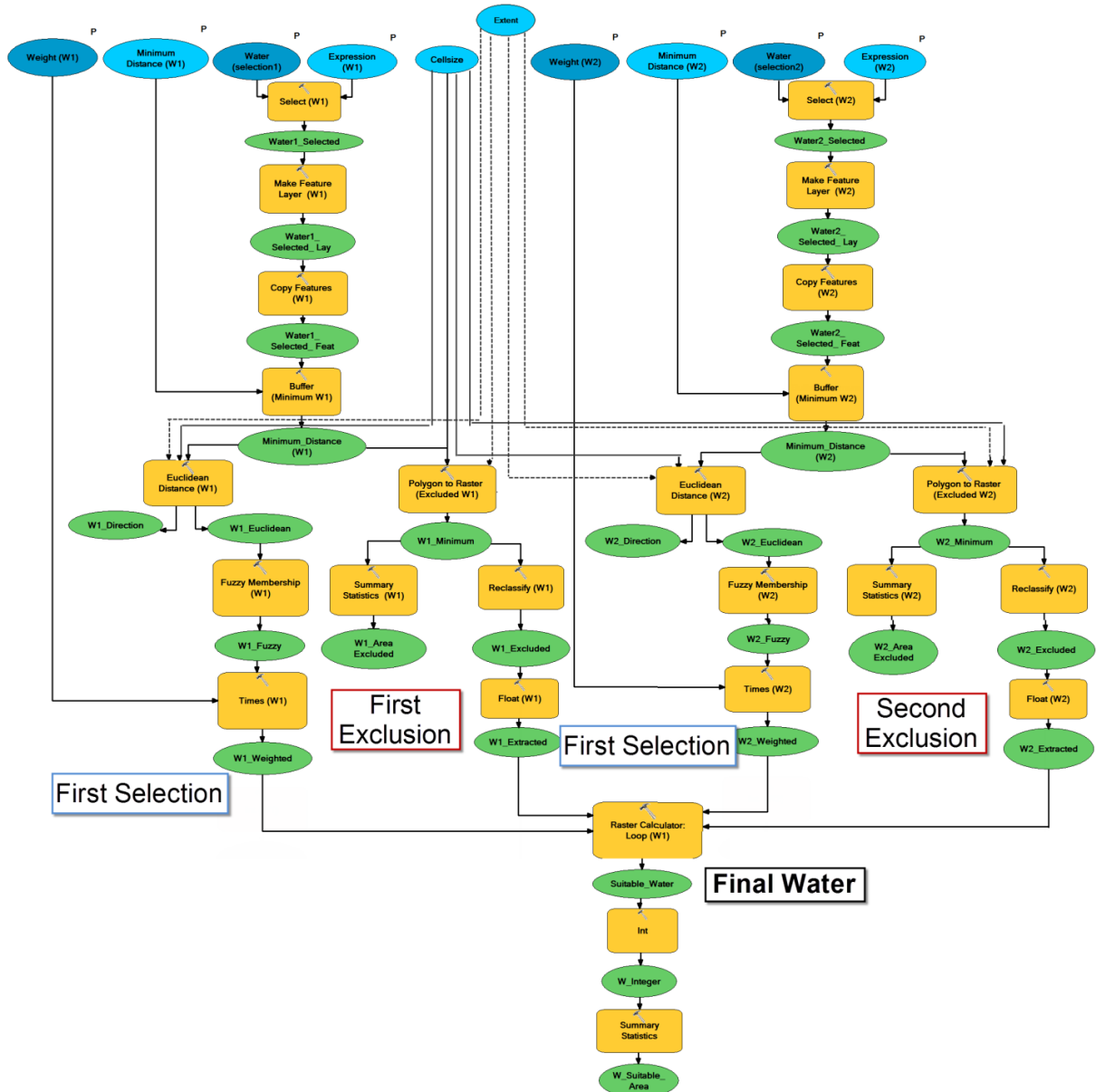


Figure 86: Water in model 3. Water bodies are selected from two input vectors, erasing then and their surroundings in the final site selection. Rest of areas is assigned a weight of suitability proportionally to distance.

8 Restricted or protected areas

A minimum distance is also required from protected areas because of historical, sacred and archeological reasons or from incompatible land uses such as airports and military areas. Model 1 has not considered this criterion and model 2 and 3 follow the same spatial analysis applied to first selection of land uses, allowing the processing of five vector inputs.

9 Natural protected areas

Also natural protected areas need to be taking into account during site selection, since wind turbines might affect relevant or vulnerable habitats, ecosystems and species.

Model 1 (from figure 87 to 91): Protected areas are of special interest for LUBW and UM, being the main restrictive criterion. Thirteen natural protected areas and their surroundings are excluded in the final site selection. They have been organized in two submodels:

- I. Ausschlussflächen (areas of exclusion) which processes six polygon shapefiles: Bannwald_Schonwald (including protective forests against avalanches and forest reserves), Biosphaerengebiet (biosphere reserve), Biotope, Flächennaturdenkmäler (FND, Natural monuments), Naturschutzgebiete (NSG, natural reserve) and SPA (Special Protection Areas) with special relevant. An overview of this model is given in the next sketch. Figure 89 represents an example of a geoprocessing applied to the first six inputs and figure 90 the geoprocessing applied to SPAs with special relevant.

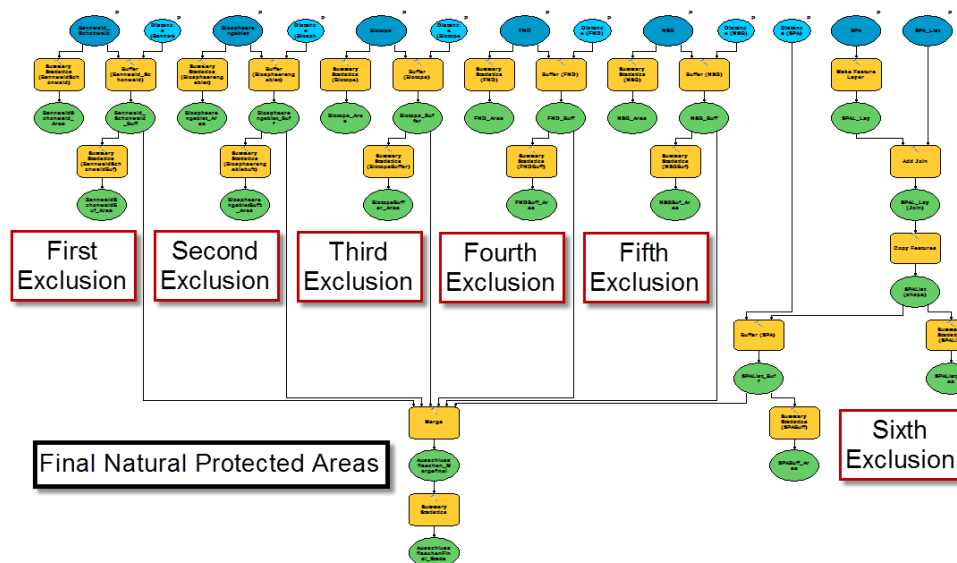


Figure 87: Ausschlussflächen model. The model *Ausschlussflächen* (areas of exclusion) processes six inputs of natural protected areas in order to exclude them and their surroundings from final site selection. An example of an input geoprocessing is represented in figure 89.

II. *Prüfungsflächen* (areas of examination) which includes seven polygon shapefiles: Fauna-Flora-Habitat Richtlinie (FFH, fauna, flora and habitat protection), Landschaftsschutzgebiet (LSG, Landscape Protected Area), Naturpark (Nature Park), rest of SPAs and three shapefiles in order to protect the specie Western Capercaillie (Auerhuhn) and its habitat. Although next figure offers an overview of the model, a zoom in can be found in figure 89.

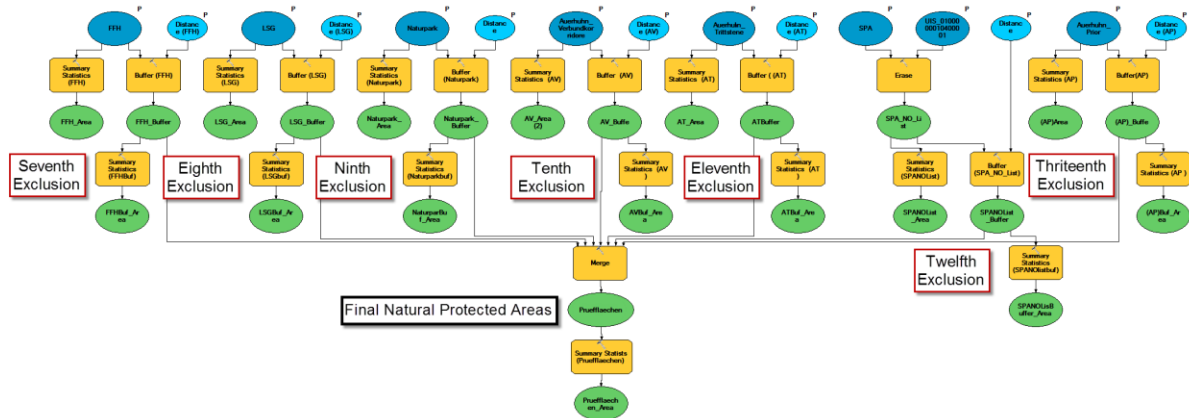


Figure 88 Prüfungsflächen model. The model *Prüfungsflächen* (areas of examination) processes seven inputs of natural protected areas in order to exclude them and their surroundings from final site selection. An example of an input geoprocessing is represented in figure 89.

All the input features are buffered according to a minimum distance inserted by users, erasing them and their surroundings from suitable wind resources (see figure 92) in order to minimize impacts on natural protected areas. “**Summary statistics**” indicate users the total area before and after the “**Buffer**” tool in order to notice the reduction of suitable area by the introduced distance. figure 89 shows an example of geoprocessing for an input shapefile.

Since LUBW differentiates between SPAs which are of a specific importance (listed in a given excel sheet) and rest of SPAs, additional tools are included inside its workflow:

- In case of Ausschlussflächen model (see figure 90), first “**Make feature Layer**” creates a temporary layer from SPA shapefile in order to manipulate data without affecting original features. Then “**Add join**” joins the excel sheet containing SPAs of special interest and match them with the created layer, obtaining a temporal vector where all the matched records are representing (SPAs within the list). Afterwards, “**Copy features**” stored them in a permanent feature class which will be processed as rest of inputs.
- Inside the *Prüfungsflächen* model (see figure 91), the output of SPA generated in the previous submodel (SPA with species on the list) is erased from the source vector in order to obtain a vector with SPA which species are not on that list. Then, they are processed as rest of inputs.

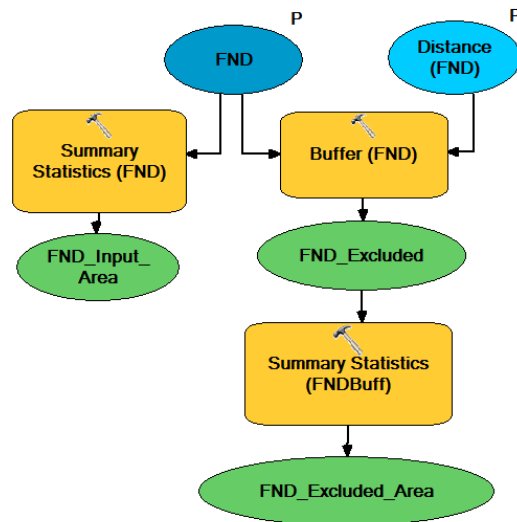


Figure 89: Geoprocessing of FND in Ausschlussflächen model.

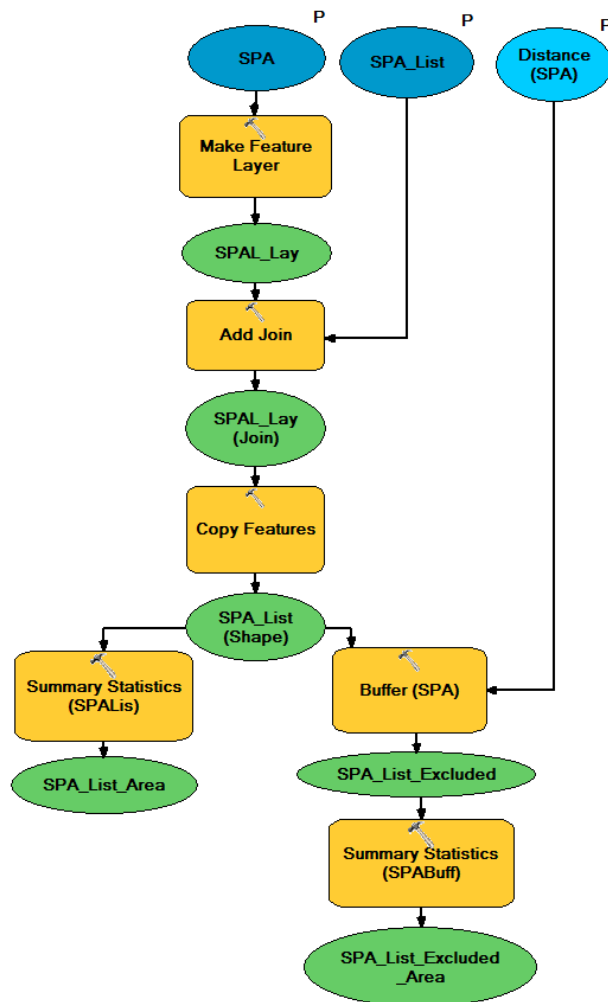


Figure 90: Geoprocessing of SPAs in the list.

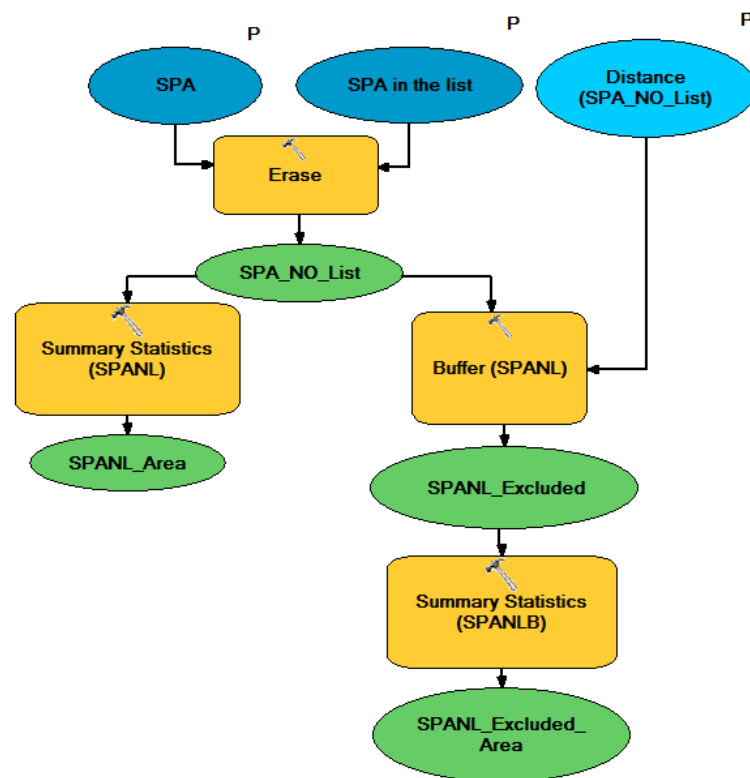


Figure 91: Geoprocessing of SPAs not in the list.

Model 2 and 3 process six input vectors with the same analysis than for the first selections of Land use models but without selecting features. The reason behind is that legislation normally obliges to keep a certain distance from a concrete figure of protection and not for a concrete element of that figure.

Combination of models

Model 1: Models are processed in a sequence where after selection of suitable wind resources is performed, outputs of following submodels are erased one by one (see figure 92) so that “Summary statistics”. Can indicate how much suitable areas are left after each erase.

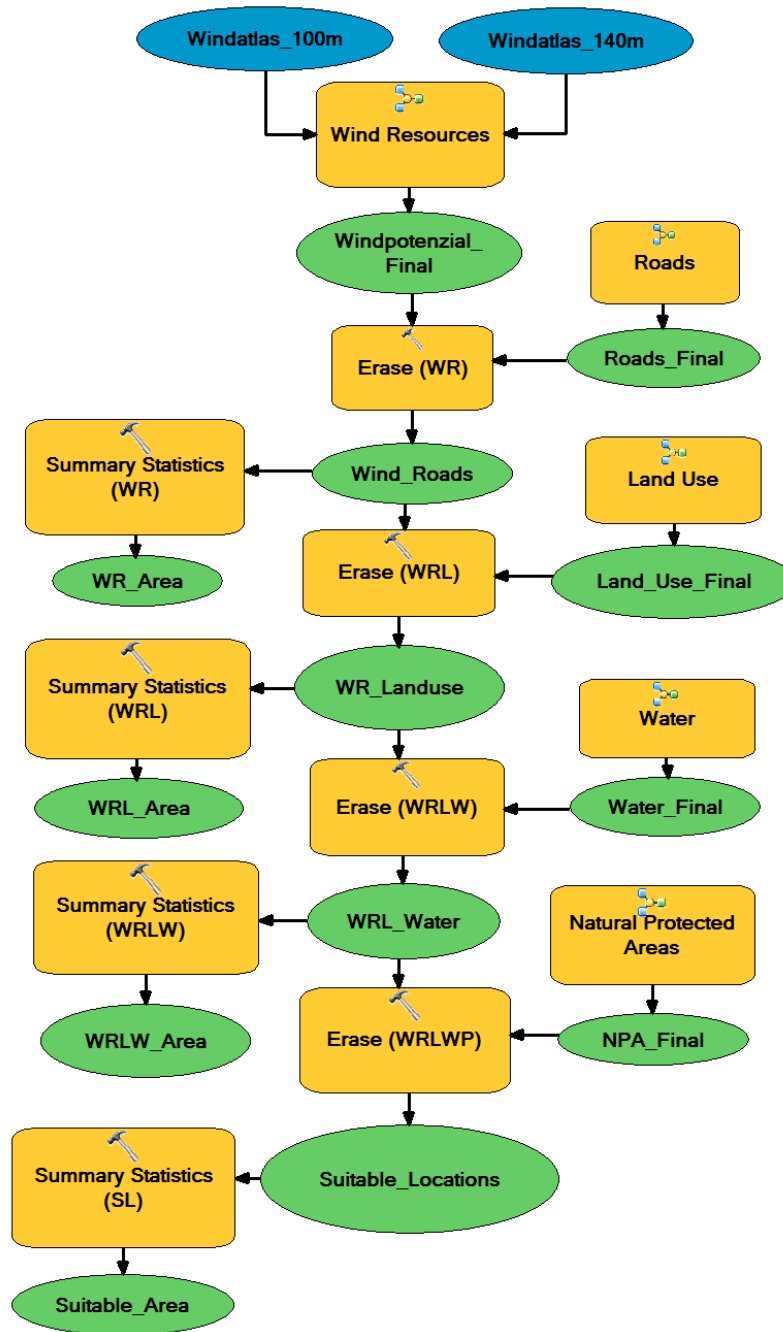


Figure 92: Complete model 1.

Model 2 and 3 (figure 93): Since model 3 can be considered as a variant of model 2, combination of all the submodels follows the same connections. All their outputs are added by “Raster calculator”, where each cell indicates how many conditions of suitability are present inside it. On the other side, NoData cells (which indicate no suitable or desired areas) are automatically erased.

As result, the output raster provides information about location of all the possible locations for wind farms and how suitable they are. Since it is a floating-point raster, it must be converted to integer to calculate final area.

Furthermore, all the submodels are connected to the output of wind resources model in order to use same cell size and extend.

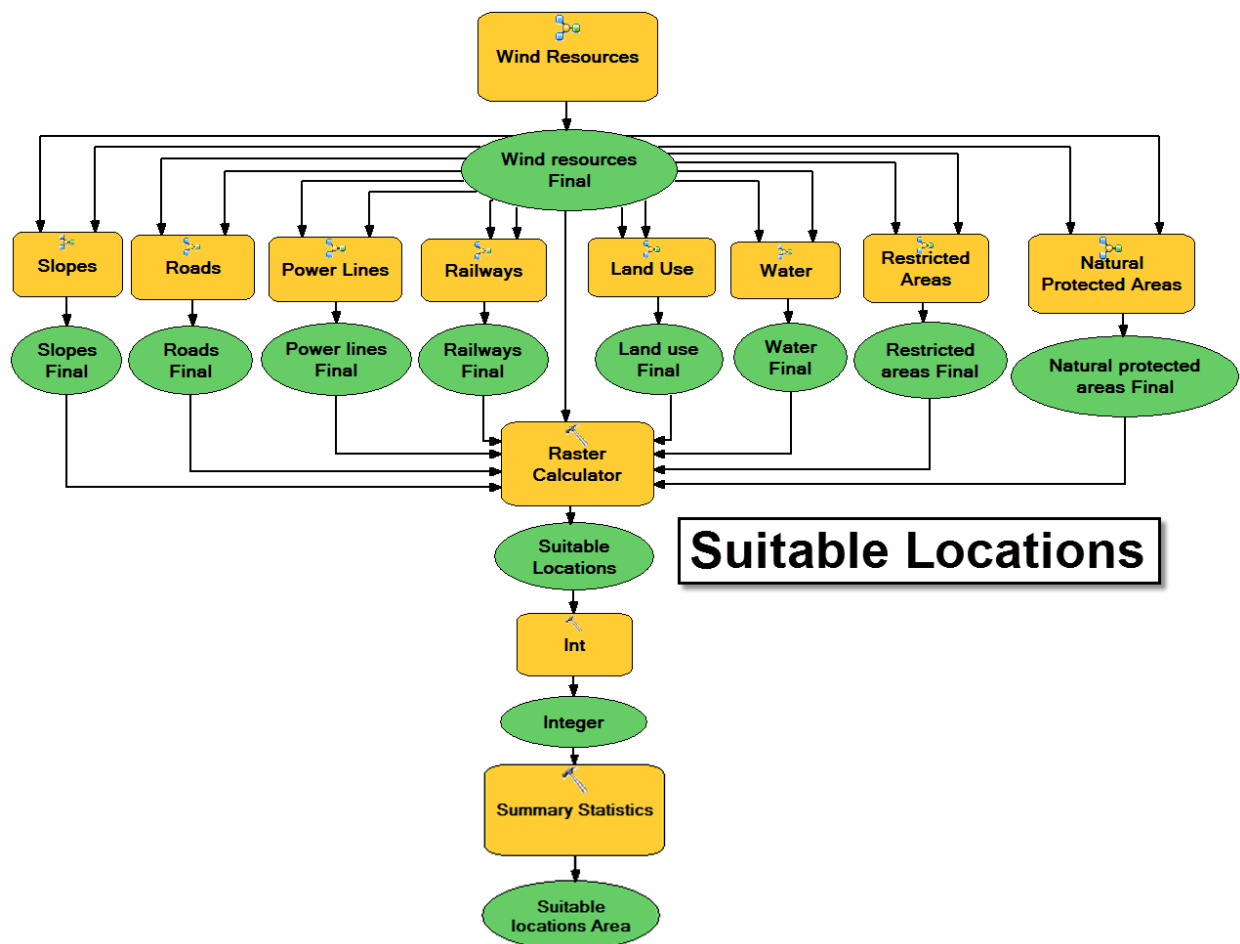


Figure 93: Entire model 2 and 3. Combination of all the submodels to generate the entire models 2 and 3.

ANNEX II: Menus and pop up messages

The entire interface has been programmed with messages that pop up when users place the cursor on highlighted elements in order to provide additional relevant information (see figure 94).

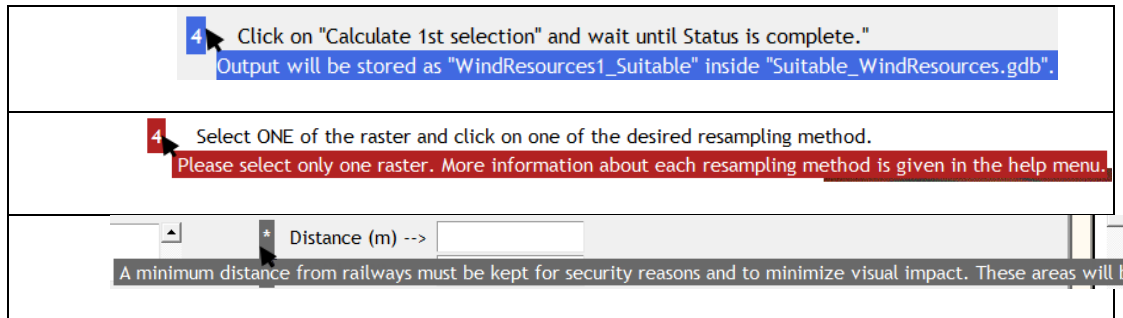


Figure 94: User friendly: Pop up messages.

Besides, three menus have been created in the menu bar containing detailed information about wind energy, SDSS and how to fulfill this application (see figure 96). Some examples are given from figure 96 to 99.

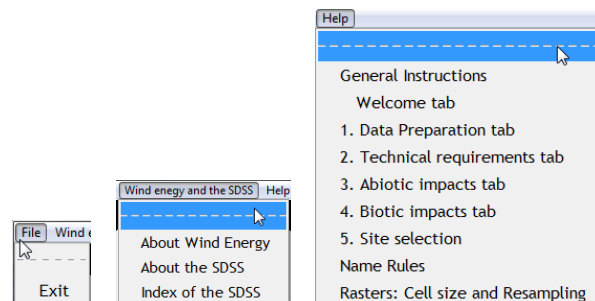


Figure 95: Menus.

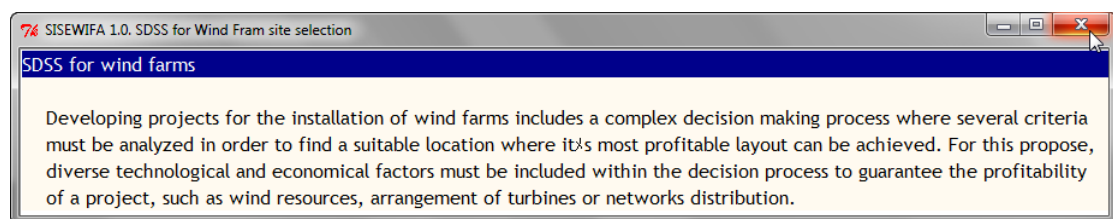


Figure 96: Wind energy and the SDSS menu: About SDSS.

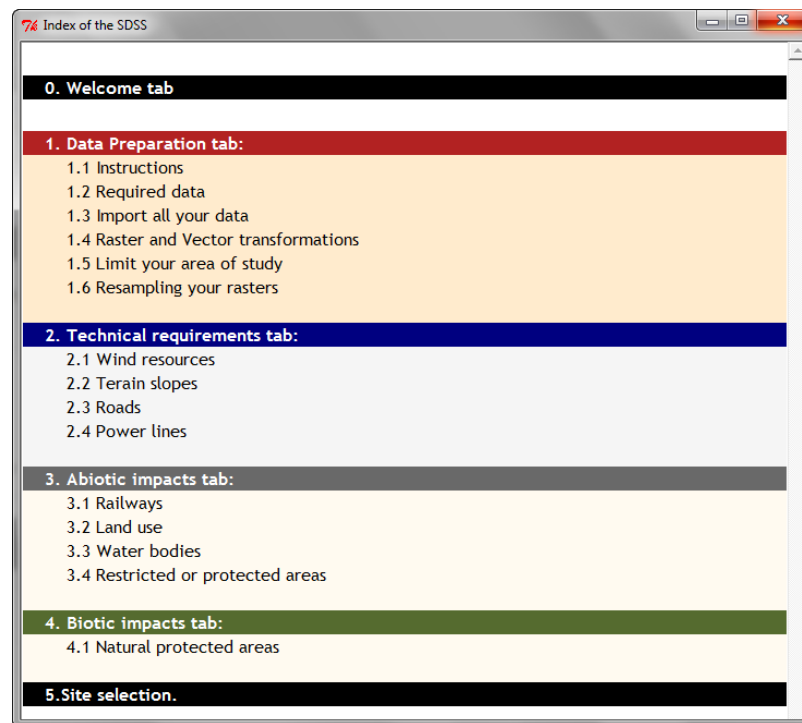


Figure 97: Wind energy and the SDSS menu: Index of the SDSS.

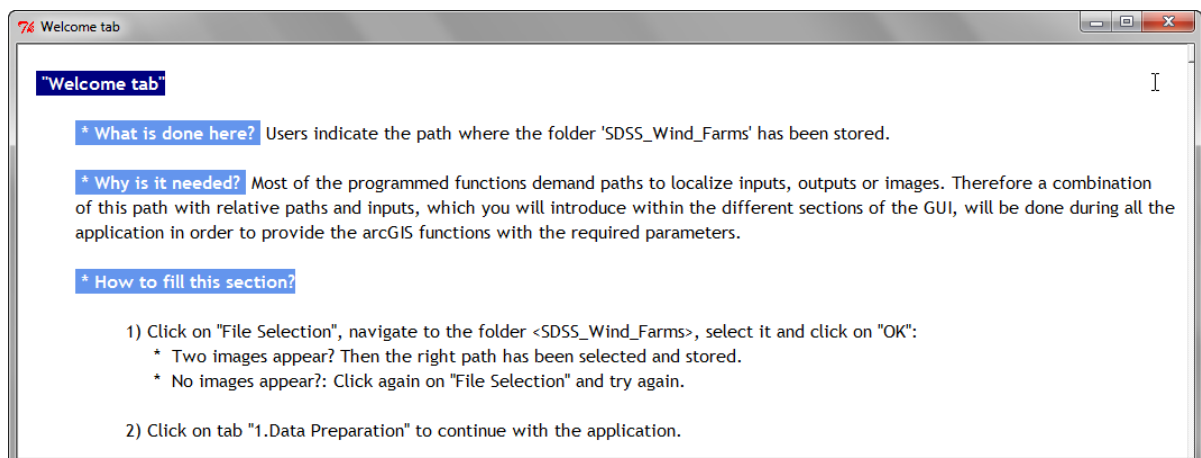


Figure 98: Help menu: Welcome tab.

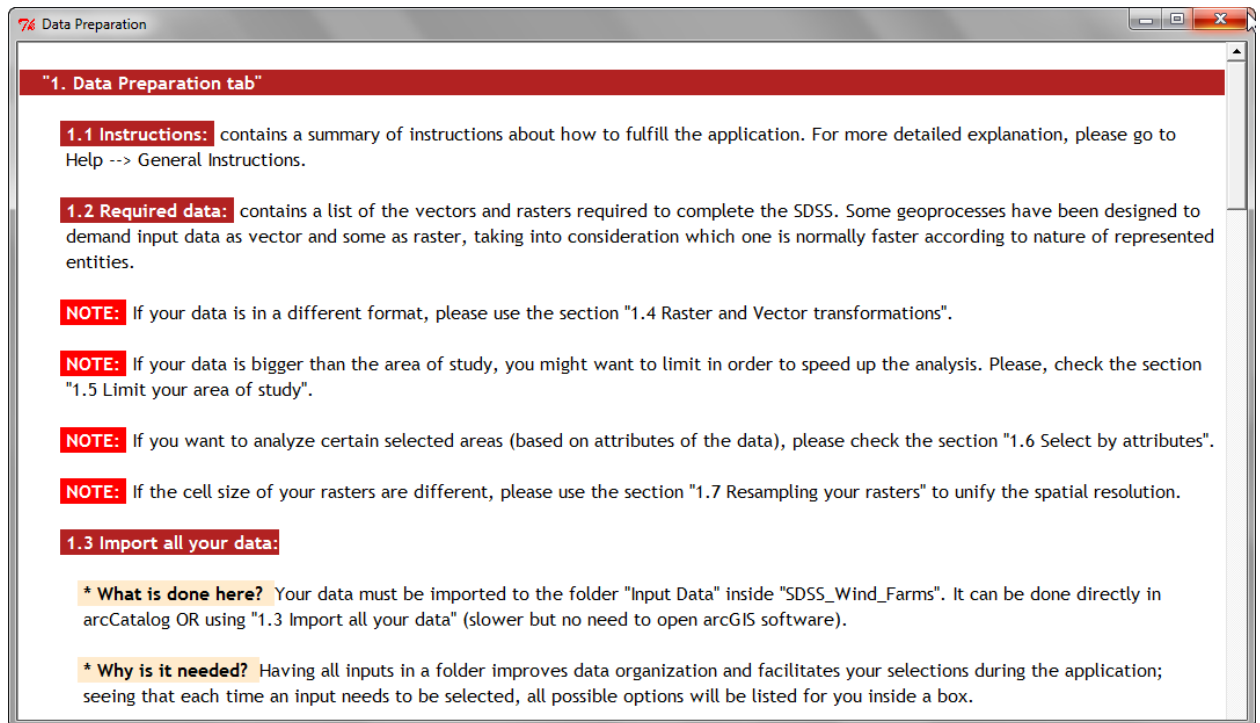


Figure 99: Help menu: Data preparation.

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