A conceptual model for the estimation of flood damage to power grids

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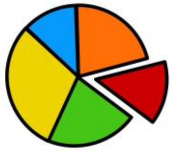
Literature review

Why floods?

- Floods are the among the most frequent and destructive natural hazards worldwide (UNDRR, 2019).
- Increase in the frequency and intensity of flood events due to climate change and anthropogenic processes (Hall et al., 2014).

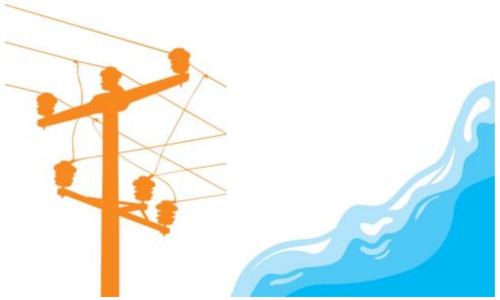
Why infrastructures?

- Infrastructures can suffer high economic losses in case of flood events as compared to other sectors (Thieken et al., 2016).
- However, flood damage modelling to infrastructures is still a challenging task (Jongman et al., 2012) due to:
  - the complexity of networks and their interconnections
  - the lack of knowledge and data to investigate damage mechanisms and to validate and calibrate damage models



Why power grids?

- Power grids constitute the backbone of modern societies and economies.
- Floods affect the power supply regularly and result in major power outages.
- Modeling and mapping flood risk in power grids enables:
  - the mitigation of flood damage
  - the reduction of the economic losses



Research aim and objectives

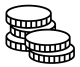
The conceptual model has been conceived to:

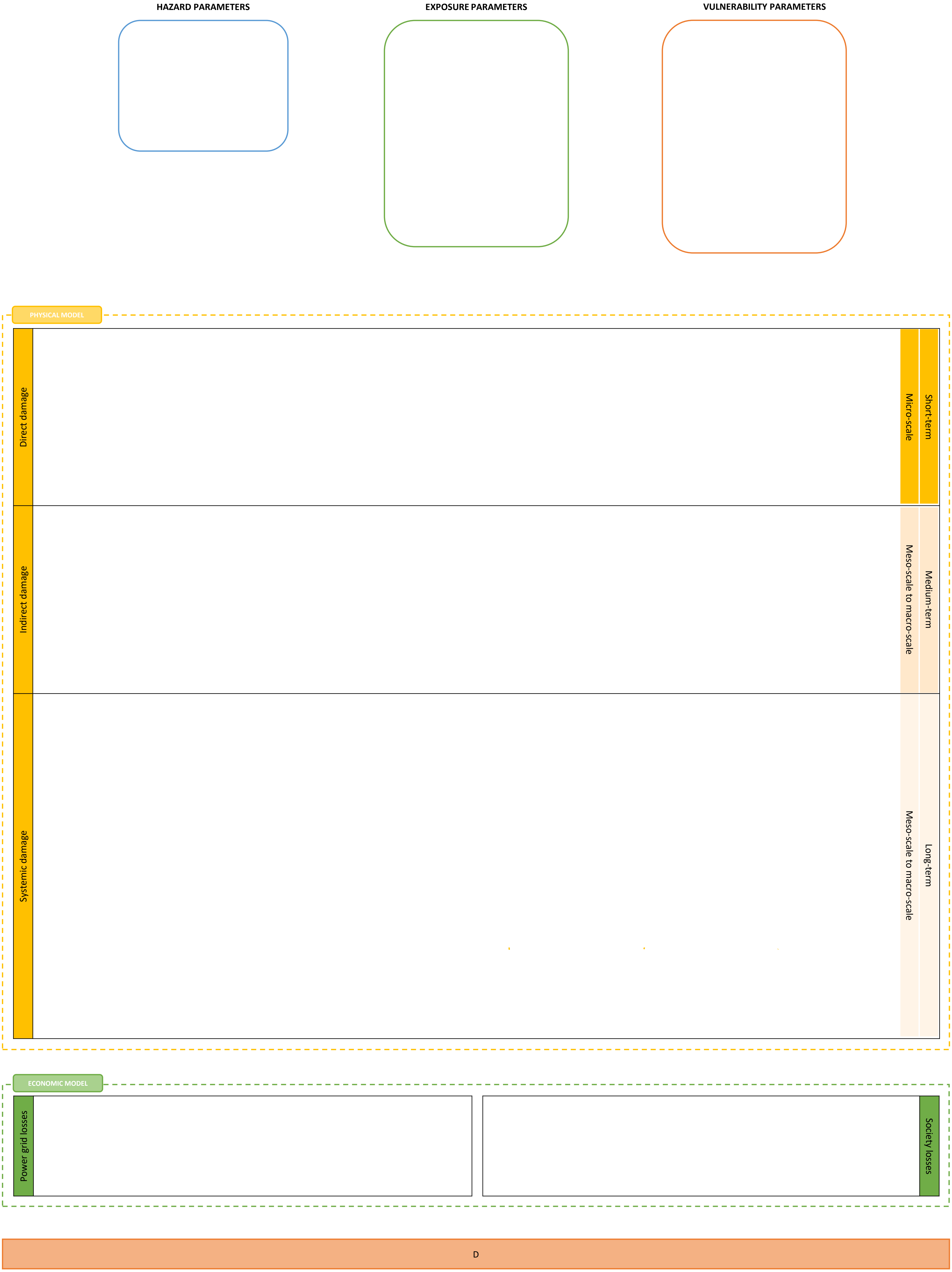
- handle the complexity of damage mechanisms
- identify the full range of cascading effects
- adopt an interdisciplinary and multi-scale evaluation approach

The conceptual model highlights:

- the different components of flood damage for which a model is required (i.e., direct, indirect, and systemic)
- the interconnections among power grids and residential, commercial, industrial sector and other infrastructures
- the hazard, exposure, and vulnerability parameters on which damage depend on
- the temporal and spatial scales of analysis

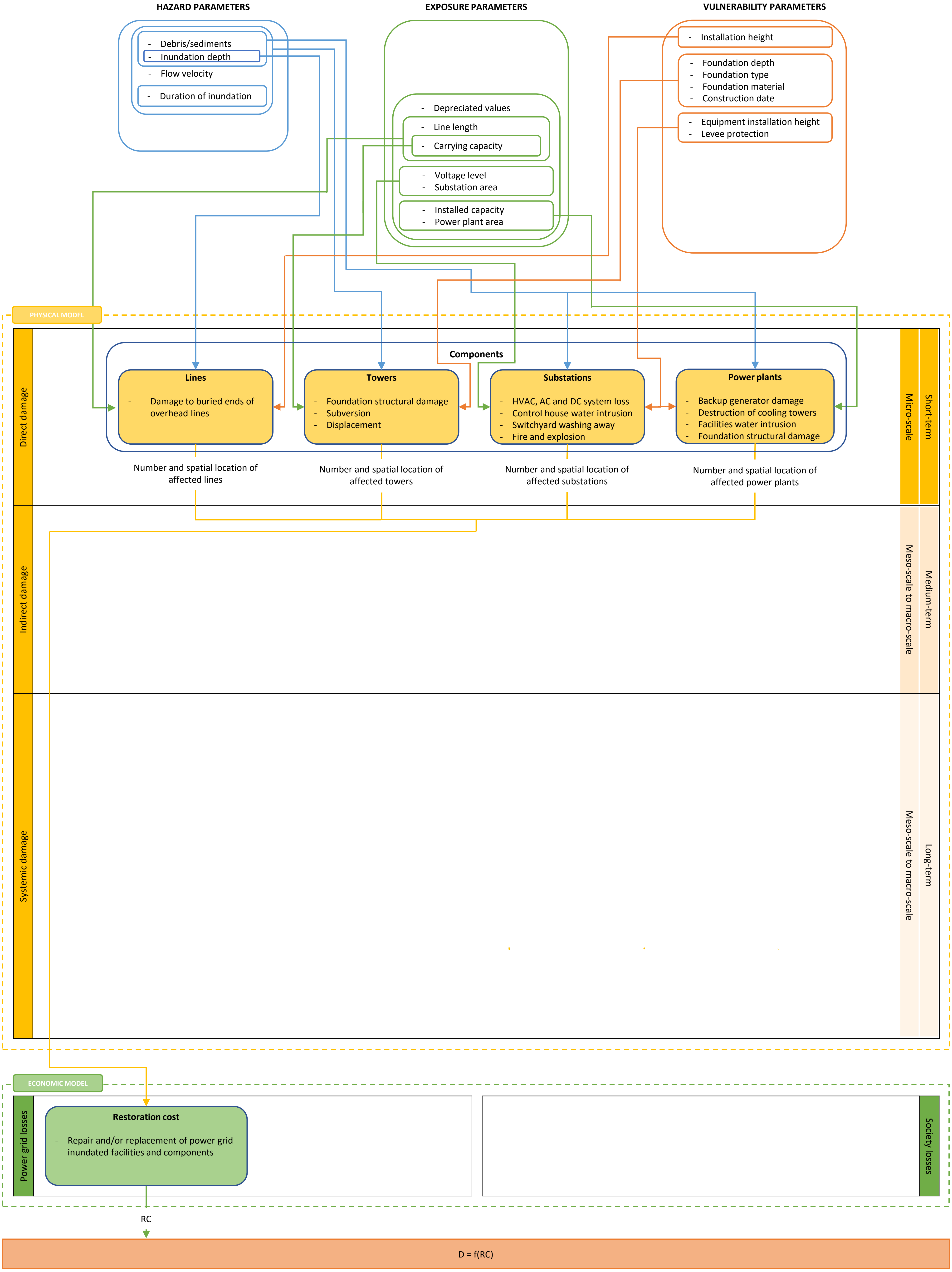
The framework of the assessment is divided into:

- physical model → flood damage in quantitative terms (e.g., number of substations affected, duration of power outage, etc.) 
- economic model → economic losses in monetary values (e.g., wages, revenues) 


HAZARD PARAMETERS
EXPOSURE PARAMETERS
VULNERABILITY PARAMETERS
PHYSICAL MODEL
Direct damage
Micro-scale
Short-term
Indirect damage
Meso-scale to macro-scale
Medium-term
Systemic damage
Meso-scale to macro-scale
Long-term
ECONOMIC MODEL
Power grid losses
Society losses
D

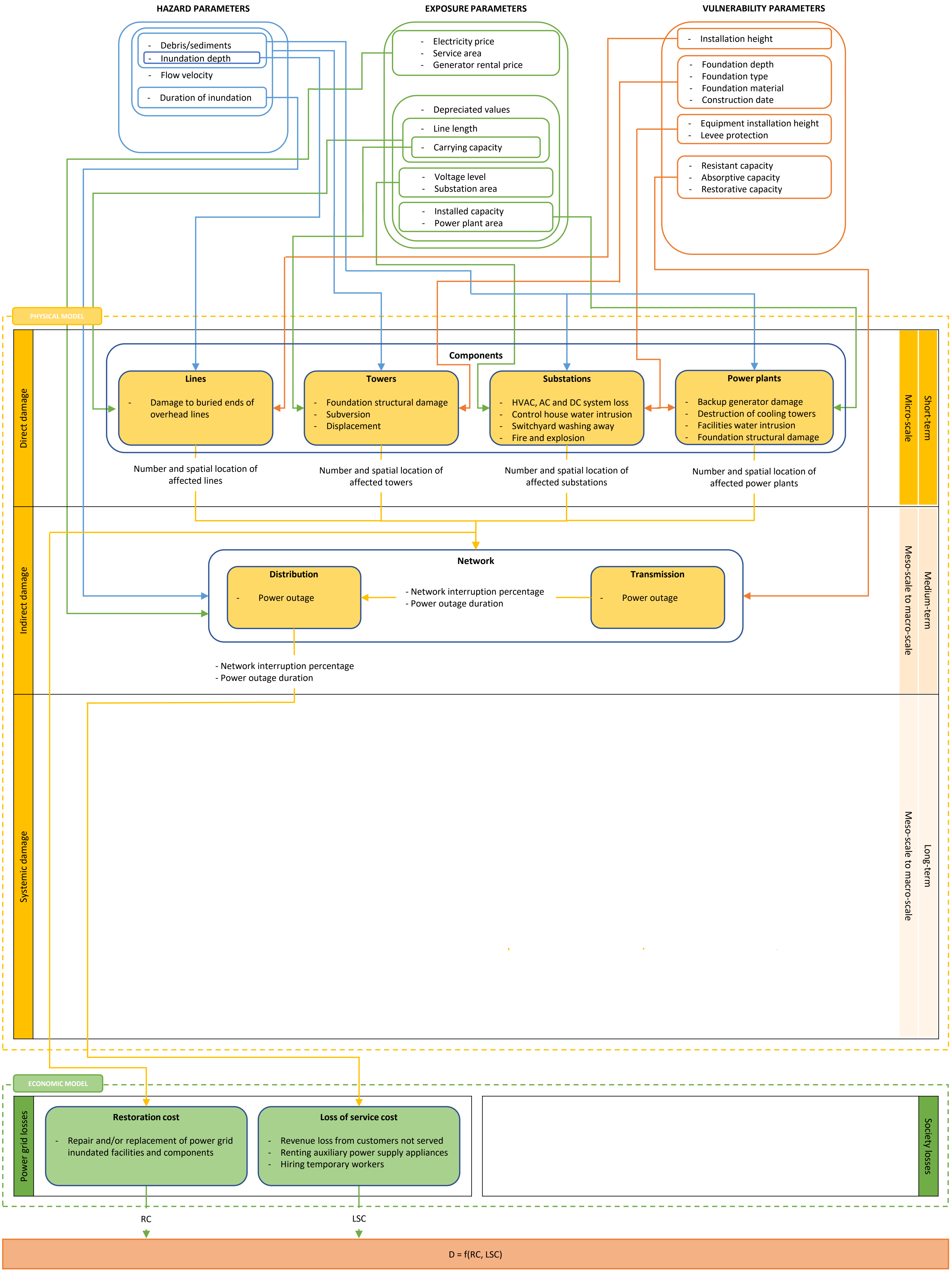
Conceptual model
1. Direct damage

Component	Damage mechanisms	References	Hazard	Exposure	Vulnerability	Scale of analysis	
						Spatial	Temporal
Lines	Damage to buried ends of overhead lines	FEMA, 2009	Inundation depth	Carrying capacity, line length	Installation height	Micro	Short-term
Towers	Foundation structural damage, subversion, displacement	Powerlink Queensland, 2011; Booth et al. 2017	Inundation depth, flow velocity, duration of inundation, debris/sediments	Carrying capacity	Foundation depth, foundation type, foundation material, construction date	Micro	Short-term
Substations	HVAC, AC and DC system loss, control house water intrusion, switchyard washing away, fire and explosion	Ward, 2013; Boggess et al., 2014; Karagiannis et al., 2017; New York Power Authority et al., 2017	Inundation depth, debris/sediments	Voltage level, substation area	Installation height, levee protection	Micro	Short-term
Power plants	Backup generators damage, destruction of cooling towers, facilities water intrusion, foundation structural damage	Srinivasan and Rethinaraj, 2013; McCall et al., 2016; New York Power Authority et al., 2017	Inundation depth, debris/sediments	Installed capacity, power plant area	Installation height, levee protection	Micro	Short-term


HAZARD PARAMETERS
- Debris/sediments
- Inundation depth
- Flow velocity
- Duration of inundation
EXPOSURE PARAMETERS
- Depreciated values
- Line length
- Carrying capacity
- Voltage level
- Substation area
- Installed capacity
- Power plant area
VULNERABILITY PARAMETERS
- Installation height
- Foundation depth
- Foundation type
- Foundation material
- Construction date
- Equipment installation height
- Levee protection
PHYSICAL MODEL
Direct damage
Components
Lines
- Damage to buried ends of overhead lines
Towers
- Foundation structural damage
- Subversion
- Displacement
Substations
- HVAC, AC and DC system loss
- Control house water intrusion
- Switchyard washing away
- Fire and explosion
Power plants
- Backup generator damage
- Destruction of cooling towers
- Facilities water intrusion
- Foundation structural damage
Number and spatial location of affected lines
Number and spatial location of affected towers
Number and spatial location of affected substations
Number and spatial location of affected power plants
Micro-scale
Short-term
Indirect damage
Meso-scale to macro-scale
Medium-term
Systemic damage
Meso-scale to macro-scale
Long-term
ECONOMIC MODEL
Power grid losses
Restoration cost
- Repair and/or replacement of power grid inundated facilities and components
Society losses
RC
D = f(RC)

Conceptual model
2. Indirect damage

Network	Damage mechanisms	References	Hazard	Exposure	Vulnerability	Scale of analysis	
						Spatial	Temporal
Transmission	Power outage	Bollinger and Dijkema 2016; Espinoza et al., 2016; Murdock et al., 2018; Karagiannis et al., 2019;	Duration of inundation	Electricity price, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity	Meso to macro	Medium-term
Distribution	Power outage	Vasenev et al., 2016; Bragatto et al., 2019; Sanchez-Munoz et al., 2020	Duration of inundation	Electricity price, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity	Meso	Medium-term



HAZARD PARAMETERS
- Debris/sediments
- Inundation depth
- Flow velocity
- Duration of inundation
EXPOSURE PARAMETERS
- Electricity price
- Service area
- Generator rental price
- Depreciated values
- Line length
- Carrying capacity
- Voltage level
- Substation area
- Installed capacity
- Power plant area
VULNERABILITY PARAMETERS
- Installation height
- Foundation depth
- Foundation type
- Foundation material
- Construction date
- Equipment installation height
- Levee protection
- Resistant capacity
- Absorptive capacity
- Restorative capacity
PHYSICAL MODEL
Direct damage
Components
Lines
- Damage to buried ends of overhead lines
Towers
- Foundation structural damage
- Subversion
- Displacement
Substations
- HVAC, AC and DC system loss
- Control house water intrusion
- Switchyard washing away
- Fire and explosion
Power plants
- Backup generator damage
- Destruction of cooling towers
- Facilities water intrusion
- Foundation structural damage
Number and spatial location of affected lines
Number and spatial location of affected towers
Number and spatial location of affected substations
Number and spatial location of affected power plants
Micro-scale
Short-term
Indirect damage
Network
Distribution
- Power outage
- Network interruption percentage
- Power outage duration
Transmission
- Power outage
- Network interruption percentage
- Power outage duration
Meso-scale to macro-scale
Medium-term
Systemic damage
Meso-scale to macro-scale
Long-term
ECONOMIC MODEL
Power grid losses
Restoration cost
- Repair and/or replacement of power grid inundated facilities and components
Loss of service cost
- Revenue loss from customers not served
- Renting auxiliary power supply appliances
- Hiring temporary workers
Society losses
RC
LSC
D = f(RC, LSC)

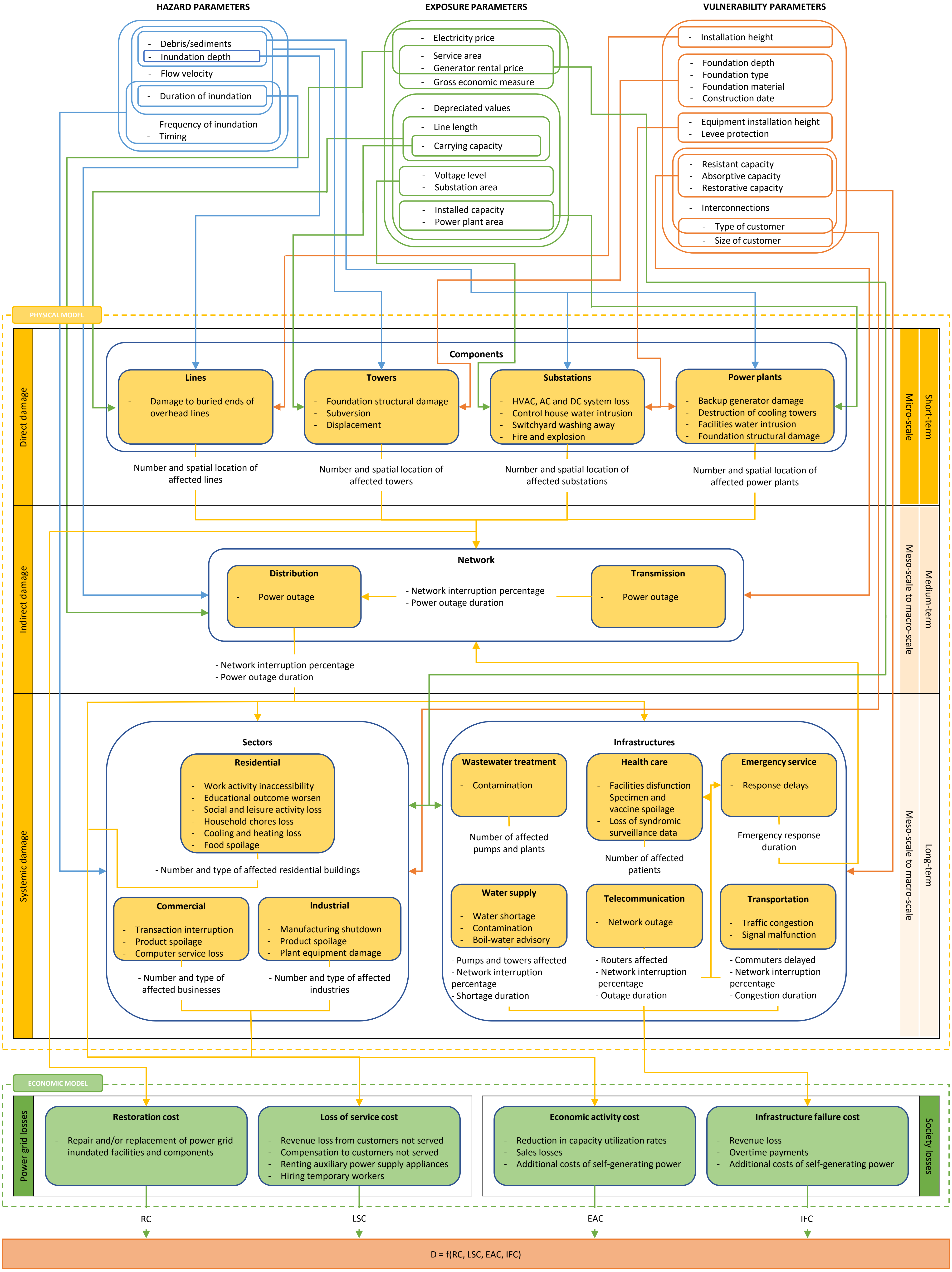
Conceptual model

3. Systemic damage

Sector	Damage mechanisms	References	Hazard	Exposure	Vulnerability	Scale of analysis	
						Spatial	Temporal
Residential	Household chores loss, social and leisure activity loss, work activity inaccessibility, food spoilage, cooling and heating loss, educational outcome worsen	Pasha and Saleem, 2013; Lenz et al., 2017	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Type of customer, size of customer	Meso to macro	Long-term
Commercial	Financial transaction interruption, computer service loss, product spoilage	Corwin and Miles., 1978; Kile et al., 2005	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Type of customer, size of customer	Meso to macro	Long-term
Industrial	Manufacturing shutdown, product spoilage, plant equipment damage	Corwin and Miles., 1978; Rentschler et al., 2019	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Type of customer, size of customer	Meso to macro	Long-term

Conceptual model
3. Systemic damage

Infrastructure	Damage mechanisms	References	Hazard	Exposure	Vulnerability	Scale of analysis	
						Spatial	Temporal
Water supply	Water shortage, contamination, boil-water advisory	Holden et al., 2013; Ebacher et al., 2010; Kile et al., 2005	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity, interconnections	Meso to macro	Long-term
Telecommunication	Network outage	Kile et al., 2005	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity, interconnections	Meso to macro	Long-term
Transportation	Traffic congestion, signal malfunction		Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity, interconnections	Meso to macro	Long-term
Wastewater treatment	Contamination	Corwin and Miles., 1978; Kile et al., 2005; Beatty et al., 2006	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity, interconnections	Meso to macro	Long-term
Health care	Non-functioning of health care activities, increase of emergency medical services calls, increase of emergency departments visits, laboratory specimen and vaccine spoilage, loss of syndromic surveillance data	Corwin and Miles., 1978; Greenwald et al., 2004; Prezant et al., 2005; Rand et al., 2005; Beatty et al., 2006; Freese et al., 2006; Klinger et al. 2014	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity, interconnections	Meso to macro	Long-term
Emergency service	Response delays	Corwin and Miles., 1978; Karagiannis et al., 2017	Duration of inundation, frequency of inundation, timing	Gross economic measure, service area, generator rental price	Resistant capacity, absorptive capacity, restorative capacity, interconnections	Meso to macro	Long-term


HAZARD PARAMETERS
EXPOSURE PARAMETERS
VULNERABILITY PARAMETERS
- Debris/sediments
- Inundation depth
- Flow velocity
- Duration of inundation
- Frequency of inundation
- Timing
- Electricity price
- Service area
- Generator rental price
- Gross economic measure
- Depreciated values
- Line length
- Carrying capacity
- Voltage level
- Substation area
- Installed capacity
- Power plant area
- Installation height
- Foundation depth
- Foundation type
- Foundation material
- Construction date
- Equipment installation height
- Levee protection
- Resistant capacity
- Absorptive capacity
- Restorative capacity
- Interconnections
- Type of customer
- Size of customer
PHYSICAL MODEL
Direct damage
Components
Lines
- Damage to buried ends of overhead lines
Towers
- Foundation structural damage
- Subversion
- Displacement
Substations
- HVAC, AC and DC system loss
- Control house water intrusion
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Power plants
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Number and spatial location of affected lines
Number and spatial location of affected towers
Number and spatial location of affected substations
Number and spatial location of affected power plants
Micro-scale
Short-term
Indirect damage
Network
Distribution
- Power outage
Transmission
- Power outage
- Network interruption percentage
- Power outage duration
Meso-scale to macro-scale
Medium-term
Systemic damage
Sectors
Residential
- Work activity inaccessibility
- Educational outcome worsen
- Social and leisure activity loss
- Household chores loss
- Cooling and heating loss
- Food spoilage
- Number and type of affected residential buildings
Commercial
- Transaction interruption
- Product spoilage
- Computer service loss
Industrial
- Manufacturing shutdown
- Product spoilage
- Plant equipment damage
- Number and type of affected businesses
- Number and type of affected industries
Infrastructures
Wastewater treatment
- Contamination
Number of affected pumps and plants
Health care
- Facilities disfunction
- Specimen and vaccine spoilage
- Loss of syndromic surveillance data
Number of affected patients
Emergency service
- Response delays
Emergency response duration
Water supply
- Water shortage
- Contamination
- Boil-water advisory
- Pumps and towers affected
- Network interruption percentage
- Shortage duration
Telecommunication
- Network outage
- Routers affected
- Network interruption percentage
- Outage duration
Transportation
- Traffic congestion
- Signal malfunction
- Commuters delayed
- Network interruption percentage
- Congestion duration
Meso-scale to macro-scale
Long-term
ECONOMIC MODEL
Power grid losses
Restoration cost
- Repair and/or replacement of power grid inundated facilities and components
Loss of service cost
- Revenue loss from customers not served
- Compensation to customers not served
- Renting auxiliary power supply appliances
- Hiring temporary workers
Economic activity cost
- Reduction in capacity utilization rates
- Sales losses
- Additional costs of self-generating power
Infrastructure failure cost
- Revenue loss
- Overtime payments
- Additional costs of self-generating power
Society losses
RC
LSC
EAC
IFC
D = f(RC, LSC, EAC, IFC)

Conceptual model
4. Economic losses

Cost	Economic losses	References	Recipient
Restoration	Repair and/or replacement of power grid inundated facilities and components	Karagiannis et al., 2017	Power grid
Loss of service	Revenue loss from customers not served, compensation to customers not served, renting auxiliary power supply appliances, hiring temporary workers	Wacker and Billinton, 1989; Karagiannis et al., 2019; Obolensky et al., 2019; Sanchez-Munoz et al., 2020	Power grid
Economic activity	Reduction in capacity utilization rates, sales losses, additional costs of self-generating power	Farquharson et al., 2018; Koks et al., 2019; Rentschler et al., 2019	Society
Utility	Revenue loss, overtime payments, additional costs of self-generating power	Corwin and Miles, 1978	Society

Discussion

- **Ongoing process:**
  - Investigation of the existing methodologies and modelling approaches for the estimation of the different damage components
  - Identification of the key challenges and limitations

- **Research priorities:**
  - Evaluation of the coherence between modelling approaches
  - Validation of the model in real case study

THANK YOU!

I will be really happy to answer your questions:

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