MANUAL

VERSION 1.9.0: SOLAR ENERGY POLICY

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AGENT-BASED RENEWABLES MODEL FOR INTEGRATED SUSTAINABLE ENERGY (ARISE)

A social-energy-economy-environment (SE3) model for analysing renewable energy policy in developing countries

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Contents

Forewords

Agent-based Renewables model for Integrated Sustainable Energy (ARISE) is an output of a PhD project in the School of Earth and Environmental Science, University of Queensland. The motivation to develop ARISE is due to the absence of suitable energy model for analysing renewable energy policy in developing countries. ARISE has features of unique characteristics of developing countries, such as urban-rural analysis, income inequality, and lack of electricity access.

The main feature of ARISE is the integration of engineering, social, microeconomic, macroeconomic and environment to ensure a comprehensive assessment of a proposed policy. This manual provides descriptions of the integration process, data, assumptions and the operating standard of ARISE. However, ARISE in this version is not fully developed that the analysis scope is still limited to solar energy policy.

The purpose of this manual is to invite other researchers to assess the weakness of ARISE. The last section of the manual provides the instruction to modify ARISE for analysis in other developing countries. We offer the transparency of ARISE, allowing others to exercise and/or adapt it for their studies. We highly appreciate any feedback.

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Authors

Disclaimers

We strive to keep all crucial information, data and assumptions of ARISE to be reported in this manual. Any missing information that is reported will be corrected as soon as possible. The authors own the copyright of ARISE, data and its manual. Individual may use ARISE, data and the manual with appropriate citation. ARISE, and its findings do not necessarily represent the views of the University of Queensland, the Ministry of Energy and Mineral Resources – the Republic of Indonesia, and the LPDP – the Republic of Indonesia.

Section 1 Overview, Design Concepts, and Details (ODD)

Using the Agent-based Renewables model for Integrated Sustainable Energy (ARISE) requires NetLogo 5.3.1, developed by the Northwestern's Center for Connected Learning and Computer-Based Modeling (CCL). The full features of the current ARISE version are described as follows:

a. Purpose. ARISE aims to examine the effectiveness and the efficiency of clean energy policies in broad perspectives: techno-economic, social micro-factors, macroeconomics, and environments.
b. Entities, state variables, and scales. This ARISE version is applied to the Indonesian context with the following entities:
    i. Users who act as the government in setting policy.
    ii. The agents of rural and urban households in 34 provinces that have been segregated into 12 categories based on urban and rural areas, electricity access, and dwelling ownership status (see Figure A1).
    iii. The State-owned electricity company (PLN), which monopolizes the electricity market in Indonesia and sells electricity at regulated prices.
c. The process of overview and schedule. On each yearly simulation step, income and the number of households grow, and the impacts of incentive and regulation on the household agents, economy and environment are evaluated.
d. Design concepts are as follows:
    i. Basic principles. ARISE simulates whether the proposed policies could attract photovoltaic (PV) investments effectively and efficiently. Effectiveness is evaluated from PV capacity, while efficiency is assessed from government subsidies and environmental impacts.
    ii. Emergence. PV investments emerge if the investments are affordable and profitable. PV investment costs by rural households without electricity access should be lower than the average electricity expenditure of other rural households in a province, while investments in urban households with electricity access only occur if the benefits of PV investments are higher than the revenue requirement.
    iii. Objectives. The central government (user) sets policy scenarios, urban households seek to gain profit, and rural households without electricity access need electricity access at affordable costs.
    iv. Prediction. Household agents are concerned with their income growth, PV costs, and tariffs to buy their PV-based electricity production.
    v. Collectives. One agent in each household category represents 1,000 actual households. Each agent has income randomly assigned, based on income distribution in data of the National Socioeconomic Survey (Susenas) 2010 (BPS, 2010b).
    vi. Observation. Our analysis observes installed PV capacity, economic growth, emissions, and the consumption of steel, concrete, aluminum, and energy.
e. Initialization. The number and socioeconomic factors of households correspond to data in 2010.
f. Input data. Extended Indonesian Input-Output (IO) Table 2010, Susenas 2010, environmental impact factors, investment costs, operational and maintenance (O&M) costs and other PV technical data.

To achieve its full features, ARISE will be further developed by:

a. Analyzing micro-hydro power for rural electrification;
b. Investigating local electricity service companies' programs for rural electrification;
c. Considering all power plant technology for comprehensive analysis of on-grid electricity systems, including sectoral energy demand and peak load analysis;
d. Using electricity demand elasticities derived from empirical studies to simulate the impacts of urbanization, electricity price, economic growth, and rural electrification to new power plant planning; and
e. Considering global trends of prices for technology and energy.

Section 2 Heterogeneity of Socio-Economic of Households

Heterogeneity of ARISE is characterized by different households' incomes, which represent those households' ability to invest in PV. In Figure 2.1, households in each province are distinguished by urban and rural regions, electricity access types, and home ownership. PLN customers in the rural and urban area are assumed to invest in renewable energy only if it has economic benefits, while rural households without electricity access will invest in renewable energy if it is affordable. Homeownership status also determines the investment decision, since rented houses are not likely to have renewable energy installed (Graziano and Gillingham, 2015).

The Central Bureau of Statistics (BPS) provides socioeconomic data through the annual Susenas. Because we use the IO table 2010, our analysis also uses Susenas 2010, which has a sample of 293,715 households from the total 61,387,200 Indonesian households (BPS, 2010a, 2017). Data collected in Susenas includes income distributions, home ownership status and electricity access type for households in rural and urban areas in each province. The sampling number in Susenas 2010 is converted into an actual household number by multiplying the sampling share with the actual household number in rural and urban areas. Also, income distributions for households with PLN's electricity access, non-PLN's electricity access and no electricity access are derived from Susenas data. The growth of income and the number of households are estimated using data from Susenas 2010 and Susenas 2011. Data from Susenas is stored in Geographic Information Systems (GIS) files (i.e., map.dbf). Definitions of variables in the GIS files are shown in Table 2.1.

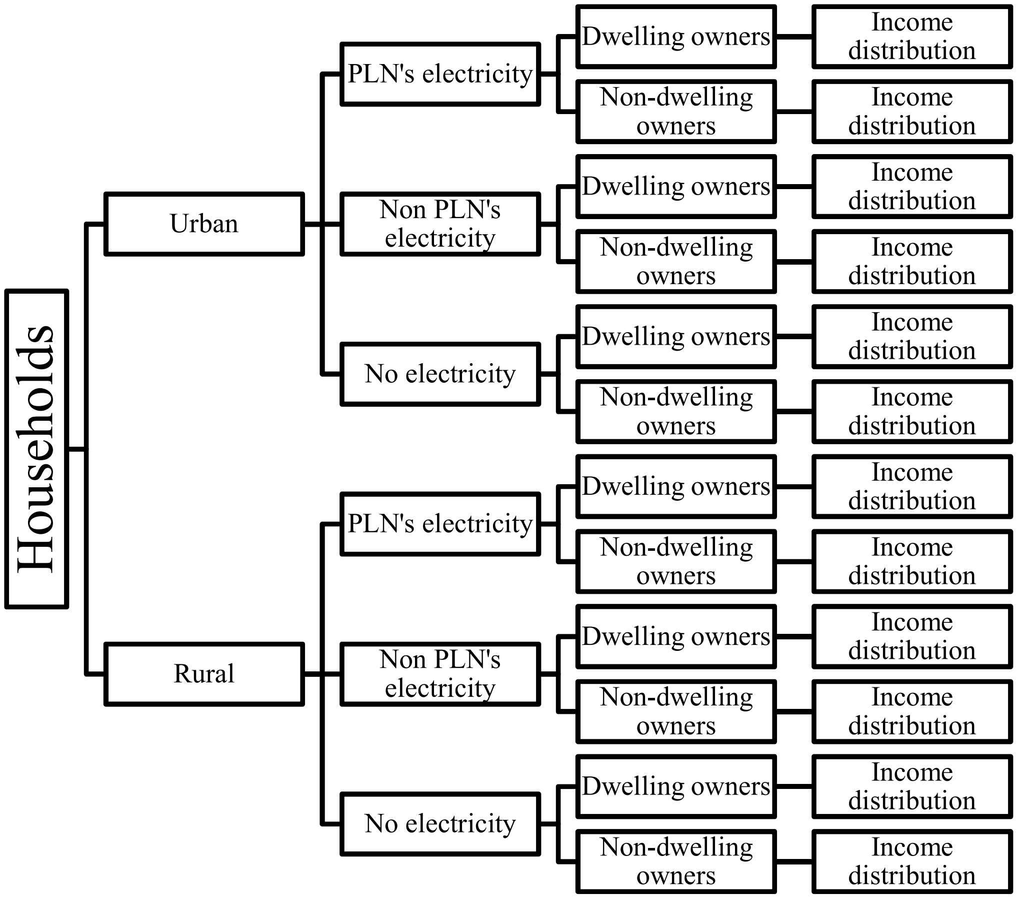

Figure 2.1 Heterogeneity of household agent

Table 2.1. Description of variables in GIS file

Name	Description	Unit
Number	Province code	
PROPINSI_	Province name, GIS file	
KODE_PROV	Numerical code for province, GIS file	
KODE	Numerical code for province, GIS file	
SHAPE_LENG	GIS Data	
SHAPE_AREA	GIS Data	
NO_HH	Number of households in 2010	households
G_HH_MIN	Minimum growth of household number	%
G_HH_MAX	Maximum growth of household number	%
G_HH_SD	Standard deviation of growth of household number	
G_HH_AVG	Average growth of household number	%
N_UPLNO	Number of urban HH with PLN owner of house	households
N_UPLNNO	Number of urban HH with PLN non-owner of house	households
N_UNPLNO	Number of urban HH without PLN owner of house	households
N_UNPLNNO	Number of urban HH without PLN non-owner of house	households
N_UNEO	Number of urban HH without electricity owner of house	households
N_UNENO	Number of urban HH without electricity non-owner of house	households
N_RPLNO	Number of rural HH with PLN owner of house	households
N_RPLNNO	Number of rural HH with PLN non-owner of house	households
N_RNPLNO	Number of rural HH without PLN owner of house	households
N_RNPLNNO	Number of rural HH without PLN non-owner of house	households
N_RNEO	Number of rural HH without electricity owner of house	households
N_RNENO	Number of rural HH without electricity non-owner of house	households
IM_UPLNO	Mean monthly expenditure of urban HH with PLN owner of house	IDR
ID_UPLNO	Standard deviation of monthly expenditure of urban HH with PLN owner of house	
IMI_UPLNO	Minimum monthly expenditure of urban HH with PLN owner of house	IDR

IMA_UPLNO	Maximum monthly expenditure of urban HH with PLN owner of house	IDR
IM_UPLNNO	Mean monthly expenditure of urban HH with PLN non-owner of house	IDR
ID_UPLNNO	Standard deviation of monthly expenditure of urban HH with PLN non-owner of house	
IMI_UPLNNO	Minimum monthly expenditure of urban HH with PLN non-owner of house	IDR
IMA_UPLNNO	Maximum monthly expenditure of urban HH with PLN non-owner of house	IDR
IM_UNPLNO	Mean monthly expenditure of urban HH without PLN owner of house	IDR
ID_UNPLNO	Standard deviation of monthly expenditure of urban HH without PLN owner of house	
IMI_UNPLNO	Minimum monthly expenditure of urban HH without PLN owner of house	IDR
IMA_UNPLNO	Maximum monthly expenditure of urban HH without PLN owner of house	IDR
IM_UNPLNNO	Mean monthly expenditure of urban HH without PLN non-owner of house	IDR
ID_UNPLNNO	Standard deviation of monthly expenditure of urban HH without PLN non-owner of house	
IMI_UNPLNNO	Minimum monthly expenditure of urban HH without PLN non-owner of house	IDR
IMA_UNPLNNO	Maximum monthly expenditure of urban HH without PLN non-owner of house	IDR
IM_UNEO	Mean monthly expenditure of urban HH without electricity owner of house	IDR
ID_UNEO	Standard deviation of monthly expenditure of urban HH without electricity owner of house	
IMI_UNEO	Minimum monthly expenditure of urban HH without electricity owner of house	IDR
IMA_UNEO	Maximum monthly expenditure of urban HH without electricity owner of house	IDR
IM_UNENO	Mean monthly expenditure of urban HH without electricity non-owner of house	IDR
ID_UNENO	Standard deviation of monthly expenditure of urban HH without electricity non-owner of house	
IMI_UNENO	Minimum monthly expenditure of urban HH without electricity non-owner of house	IDR
IMA_UNENO	Maximum monthly expenditure of urban HH without electricity non-owner of house	IDR
IM_RPLNO	Mean monthly expenditure of rural HH with PLN owner of house	IDR
ID_RPLNO	Standard deviation of monthly expenditure of rural HH with PLN owner of house	
IMI_RPLNO	Minimum monthly expenditure of rural HH with PLN owner of house	IDR
IMA_RPLNO	Maximum monthly expenditure of rural HH with PLN owner of house	IDR
IM_RPLNNO	Mean monthly expenditure of rural HH with PLN non-owner of house	IDR
ID_RPLNNO	Standard deviation of monthly expenditure of rural HH with PLN non-owner of house	
IMI_RPLNNO	Minimum monthly expenditure of rural HH with PLN non-owner of house	IDR
IMA_RPLNNO	Maximum monthly expenditure of rural HH with PLN non-owner of house	IDR
IM_RNPLNO	Mean monthly expenditure of rural HH without PLN owner of house	IDR

ID_RNPLNO	Standard deviation of monthly expenditure of rural HH without PLN owner of house	
IMI_RNPLNO	Minimum monthly expenditure of rural HH without PLN owner of house	IDR
IMA_RNPLNO	Maximum monthly expenditure of rural HH without PLN owner of house	IDR
IM_RNPLNNO	Mean monthly expenditure of rural HH without PLN non-owner of house	IDR
ID_RNPLNNO	Standard deviation of monthly expenditure of rural HH without PLN non-owner of house	
IMI_RNPLNN	Minimum monthly expenditure of rural HH without PLN non-owner of house	IDR
IMA_RNPLNN	Maximum monthly expenditure of rural HH without PLN non-owner of house	IDR
IM_RNEO	Mean monthly expenditure of rural HH without electricity owner of house	IDR
ID_RNEO	Standard deviation of monthly expenditure of rural HH without electricity owner of house	
IMI_RNEO	Minimum monthly expenditure of rural HH without electricity owner of house	IDR
IMA_RNEO	Maximum monthly expenditure of rural HH without electricity owner of house	IDR
IM_RNENO	Mean monthly expenditure of rural HH without electricity non-owner of house	IDR
ID_RNENO	Standard deviation of monthly expenditure of rural HH without electricity non-owner of house	
IMI_RNENO	Minimum monthly expenditure of rural HH without electricity non-owner of house	IDR
IMA_RNENO	Maximum monthly expenditure of rural HH without electricity non-owner of house	IDR
GI_UPLNO	Income growth of urban HH with PLN owner of house	%
GI_UPLNNO	Income growth of urban HH with PLN non-owner of house	%
GI_UNPLNO	Income growth of urban HH without PLN owner of house	%
GI_UNPLNNO	Income growth of urban HH without PLN non-owner of house	%
GI_UNEO	Income growth of urban HH without electricity owner of house	%
GI_UNENO	Income growth of urban HH without electricity non-owner of house	%
GI_RPLNO	Income growth of rural HH with PLN owner of house	%
GI_RPLNNO	Income growth of rural HH with PLN non-owner of house	%
GI_RNPLNO	Income growth of rural HH without PLN owner of house	%
GI_RNPLNNO	Income growth of rural HH without PLN non-owner of house	%
GI_RNEO	Income growth of rural HH without electricity owner of house	%
GI_RNENO	Income growth of rural HH without electricity non-owner of house	%
S_UR_ELEX	Percentage of electricity expenditure in total expenditure of urban HH	%
S_RU_ELEX	Percentage of electricity expenditure in total expenditure of rural HH	%
G_URB_MO	Growth of motorcycle ownership in urban household	%

G_RU_MO	Growth of motorcycle ownership in rural household	%
R_MHP	Microhydro resource potential	MW
R_HYD	Hydro resource potential	MW
R_SUN	Solar resource potential	MW
R_WND	Wind resource potential	MW
R_GEO	Proven geothermal reserves	MW
R_BMASS	Biomass energy potential	MW
R_BGAS	Biogas energy potential	MW
FIT2017	Feed-in tariff (FIT) issued in 2017	IDR/kWh
HYD_FIT8	FIT for hydropower until 8-year operation	IDR/GWh
HYD_FIT9	FIT for hydropower after 9-year operation	IDR/GWh
GEO_FIT	Maximum FIT for geothermal (as reference in tender process)	IDR/GWh
SUN_FIT	Maximum FIT for solar energy (as reference in tender process)	IDR/GWh
WND_FIT	Maximum FIT for wind energy	IDR/GWh
LDFILL_FIT	Maximum FIT for sanitary landfill	IDR/GWh
CWASTE_FIT	Maximum FIT for city waster thermochemical Tech	IDR/GWh
BMASS_FIT	Maximum FIT for biomass	IDR/GWh
BGAS_FIT	Maximum FIT for biogas	IDR/GWh

Note: HH is households, FIT is feed-in tariff, PLN is the State-owned Electricity Company, GIS is geographic information systems, IDR is Indonesian rupiah currency, MW is megawatt and GWh is gigawatt hours.

Section 3 Electricity System Analysis

3.1 Rural Electrification

Options of electricity supply for households without electricity grid are diesel generator, PV and micro hydropower plant (Blum et al., 2013). A diesel generator is the most commonly used though it has high operational costs while most investments for PV and micro hydropower plant are still limited to governments' projects. Though government project schemes have been criticised for their unsustainability (Schmidt et al., 2013; Sovacool, 2013), renewable energy projects are always budgeted by central and local governments (MEMR, 2012, 2017b). Lack of private investment is one of the reasons while the projects also become one of election campaign agendas of local government leaders and people's representatives.

Other schemes are viewed to have better sustainability, such as community-based rural electrification (Sovacool, 2013) and IPP scheme (Schmidt et al., 2013). However, rural electrification is risky business, which requires incentives (Schmidt et al., 2013). Therefore, in 2016, the government issued a regulation that allows IPPs for rural electrification to claim electricity subsidy, maximum 84 kWh per household per month (MEMR, 2016). ARISE could simulate the effectiveness and the efficiency of the regulation. Furthermore, it also could analyse financing assistance, i.e. rebate, low-interest rate and microcredit, which have been successfully implemented in other developing countries (Sovacool, 2013).

We use international data for PV costs (IEA and NEA, 2015). Indonesia Solar Module Manufacture Association (APAMSI) released manufacture prices of PV, but the prices do not include shipping costs, taxes and balance of system (BOS) costs, which also vary between sites. Nevertheless, APAMSI prices, equivalent to USD 1,364 – 1,823/ kWp, are relatively similar to the international data, USD 1,867 – 1,939/ kWp. Table 3.1 shows default values of costs and other technical parameters in ARISE.

3.2 Interconnection Systems

As mentioned before, costs in power plant are categorised into capital costs, fix O&M costs and variable O&M costs. Similar to the analysis of rural electrification, international cost data in Table 3.1 is used for the interconnection analysis. International data is preferred for ARISE because national data is not as comprehensive as the global data. The similar strategy is also used by Blum et al. (2013) who used the World Bank data for analysing electricity generation costs in Indonesia. Domestic publication of capital cost is not available, but O&M costs are published by PLN annually. Table 3.2 compares PLN operational costs and global O&M costs. O&M costs for PV in Indonesia are very high because the capacity factor is 6.8% while the capacity factor in IEA and NEA (2015) is 17%. Nevertheless, we assume PV capacity factor in Indonesia will be improved in the future.

Fossil energy prices are projected to increase each year (BREE, 2014; EIA, 2017; IEA, 2016), influencing O&M costs of fossil energy-based power plants. On the other hand, renewable energy costs are assumed to decline due to falling technology prices and competitive tenders scheme (IRENA, 2017). For example, PV bid in Peru and India in 2010 was higher than 200 USD/ MWh, but the results of auctions in Dubai, Chile, Mexico and USA were lower than 50 USD/ MWh in 2016. IEA (2016) predicted that capital costs of wind turbine and PV in 2015 – 2040 will reduce for 10 – 60 % and 20 – 70% respectively. The mean value of the predicted reduction, 1.8% per year for PV, is assumed as declining capital cost rate until 2040 and, after that, the capital costs are expected steady.

Table 3.1 Assumptions of costs and other technical parameters (default values)

Parameters	Scenario 1
Capital subsidy (%)	100 (rural), 0 (urban)
Interest subsidy (%)	0
Loan period (years)	5
100 Wp PV price (IDR)	2,484,000
Annual OM costs (IDR)	0 (rural), 250,000 (urban)
PV lifetime (years)	2 (rural), 20 (urban)
Inverter price (IDR)	13,000,000
Cost of equity (%/ year)	15
Incentives	Feed-in tariff
Loan interest (%/years)	12
Capacity factor (%/years)	16
Value added tax (%)	10
Debt reserves (% of yearly loan instalment)	100
Inflation (%/year)	5.1
Interest rate on debt reserves (%)	1.3
Escalation (%/year)	1.0

Table 3.2 Comparison of operational costs (USD/ MWh)

Sources	PLTA	PLTU	PLTD	PLTG	PLTP	PLTGU	PLTS
PLN (2016)*	9.1	34.8	585.9	232.4	60.0	73.6	122.9
IEA and NEA (2015)**	10.6	39.7	N/A	150.3	100	74.7	19.4

*O&M costs without asset depreciation, ** Data for lowest investment costs as in Table E.2, the exchange rate used is 13,300 IDR/ USD.

Table 3.3 shows PLN's electricity generation costs, which is used as maximum prices for new IPP contract. The costs vary on each province depending on power plant mix in the region. Java, Madura & Bali (JAMALI) electricity system has the lowest electricity generation share due to the high percentage of coal power plants. By contrast, small islands heavily depending on diesel generators have costs higher than 10 cent USD/ kWh. These costs are used as a reference to negotiating electricity prices from IPPs, including IPPs in renewable energy.

MEMR (2017c) in Table 3.4 replaces previous regulations on premium FIT, stored in GIS file in Table 2.1. MEMR (2017c) regulates maximum tariff of renewable energy – based electricity that is equal to Table 3.3 in a condition that the renewable energy is developed in a province with electricity generation cost higher than the national average generation costs, i.e. 7.39 cent USD/ kWh. Otherwise, the maximum tariff is 85% of local generation costs in Table 3.3. In this version of ARISE, we assume PLN can buy electricity generated from PV in households.

Table 3.3 Regional PLN's generation costs in 2016

No	Systems/ Sub Systems	Electricity generation costs	
		IDR/kWh	Cent USD/ kWh
I. Sumatera		1,194	8.97
A. North part of Sumatera			
1. Aceh		1,383	10.39
a. Weh Island		1,733	13.02
b. Simeuleu Island		1,817	13.65
2. North Sumatera		1,235	9.28
Nias		2,049	15.40
B. Central and south parts of Sumatera			
1. West Sumatera		1,074	8.07
Mentawai archipelagos		2,096	15.75
2. Riau and Riau archipelagos		1,349	10.14
Bintan		1,583	11.90
Tanjung Balai Karimun		1,706	12.82
Natuna		2,089	15.70
Anambas		2,149	16.15
3. South Sumatera, Jambi and Bengkulu (S2JB)		1,046	7.86
Enggano island		2,322	17.45
4. Lampung		1,034	7.77
C. Bangka		1,817	13.65
D. Belitung		1,619	12.17
E. Other small island sub systems		2,096	15.75
II. Java & Bali		868	6.52
A. Jakarta		867	6.52
Thousand archipelago		2,332	17.52
B. Banten		866	6.51
Panjang island		2,332	17.52
C. West Java		866	6.51
D. Central Java		868	6.52
Karimun Java		2,332	17.52
E. East Java		870	6.54
1. Madura isolated		2,332	17.52
2. Bawean		1,964	14.76
3. Gili Ketapang		2,332	17.52
F. Bali		881	6.62
Three Nusa system (Nusa Penida, Nusa Lembongan, Nusa Ceningan)		1,745	13.11
G. Other small subsystems		2,332	17.52
III. Kalimantan		1,373	10.32
A. West Kalimantan		1,655	12.44
B. South Kalimantan & Central Kalimantan		1,203	9.04
C. East Kalimantan & North Kalimantan		1,357	10.20
D. Other small subsystems		2,332	17.52
IV. Sulawesi & Nusa Tenggara		1,421	10.68

A. North Sulawesi, Central Sulawesi & Gorontalo	1,696	12.75
1. North part of Sulawesi (Manado, Gorontalo, Kotamobagu)	1,696	12.75
2. Toli-toli	2,026	15.23
3. Tahuna	2,332	17.52
4. Palu (Grid Sulbagsel)	1,016	7.64
5. Luwuk	1,759	13.22
B. South Sulawesi, South East Sulawesi & West Sulawesi	1,078	8.10
1. South part of Sulawesi	1,016	7.64
2. Kendari	1,801	13.53
3. Bau-baru	2,137	16.06
4. Selayar	2,115	15.89
C. West Nusa Tenggara	1,821	13.68
1. Bima	1,880	14.13
2. Lombok	1,629	12.24
3. Sumbawa	1,878	14.11
D. East Nusa Tenggara	2,332	17.52
1. Sumba	1,887	14.18
2. Timor	2,226	16.73
3. West part of Flores	1,751	13.16
4. East part of Flores	2,070	15.56
E. Other small subsystems	2,332	17.52
V. Maluku & Papua	2,008	15.09
A. Maluku & North Maluku	2,305	17.32
1. Ambon	1,680	12.62
2. Seram	2,330	17.51
3. Sanana	1,626	12.22
4. Buru	1,728	12.99
5. Ternate - Tidore	1,971	14.81
6. Sanana	1,811	13.61
7. Bacan	1,811	13.61
8. Halmahera (Tobelo, Malifut, Jailolo, Sofifi, Maba)	1,685	12.66
9. Daruba	1,587	11.93
10. Tual	1,657	12.45
11. Dobo	2,063	15.50
12. Saumlaki	1,686	12.67
B. Papua & Papua Barat	1,802	13.54
1. Jayapura	2,332	17.52
2. Sarmi	1,753	13.17
3. Biak	1,778	13.36
4. Serui	1,604	12.05
5. Nabire	2,332	17.52
6. Wamena	1,786	13.42
7. Timika	1,704	12.81
8. Merauke	1,704	12.81
9. Tanah Merah	1,760	13.23

10. Manokwari	1,305	9.81
11. Sorong	2,332	17.52
12. Teminabuan	2,332	17.52
13. Fak Fak	2,332	17.52
14. Kaimana	2,332	17.52
15. Bintuni	2,332	17.52
16. Raja Ampat	2,332	17.52
C. Other small subsystems	2,332	17.52
National average generation costs	983	7.39

Source: (MEMR, 2017a)

Table 3.4 Tariffs for renewable energy in Indonesia

Power Plant Technology	Systems	Tariff	
		Local PLN costs > National average PLN costs	Local PLN costs < National average PLN costs
Solar	Quota tenders	Maximum 85% local costs	Maximum 100% local costs
Wind	Quota tenders	Maximum 85% local costs	Maximum 100% local costs
Hydro	Reference tariff	Maximum 85% local costs	Maximum 100% local costs
	Direct contract	Negotiations	
Geothermal	Reference tariff	Maximum 100% local costs	Negotiations
Biomass	Reference tariff (capacity ≤ 10 MW)	Maximum 85% local costs	Maximum 100% local costs
	Direct contract (capacity > 10 MW)	Negotiations	
Biogas	Reference tariff (capacity ≤ 10 MW)	Maximum 85% local costs	Maximum 100% local costs
	Direct contract (capacity > 10 MW)	Negotiations	
Waste to energy	Reference tariff	Maximum 100% local costs	Negotiations

Source: MEMR (2017c)

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Section 4 Macroeconomic Perspective: Input-Output (IO) Analysis

I-O analysis, developed by Wassily Leontief (1936), uses interindustry transaction table which shows the flow of output from industry i to industry j as an input and to final demand as illustrated in Table 4.1. The input-output relationship among industries in I-O table is shown by the following equation:

$$X_i = \sum_{j=1}^{n} X_{ij} + F_i + E_i - M_i = \sum_{j=1}^{n} a_{ij} X_j + F_i + E_i - M_i \quad (4.1)$$

or in matrix terms:

$$\boldsymbol{X} = \boldsymbol{AX} + \boldsymbol{F} + \boldsymbol{E} - \boldsymbol{M} \quad (4.2)$$

where $\boldsymbol{X}$ is a vector of sectoral gross outputs; $\boldsymbol{A}$ is a matric of direct input or technical coefficients; $\boldsymbol{F}$ is a vector of domestic final demand, which consists of household consumption, investment/ capital formation, and government expenditure; $\boldsymbol{E}$ is a vector of exports; and $\boldsymbol{M}$ is a vector of imports. Let total final demand $\boldsymbol{Y} = \boldsymbol{F} + \boldsymbol{E} - \boldsymbol{M}$, then:

$$\boldsymbol{X} = \boldsymbol{AX} + \boldsymbol{Y} \quad (4.3)$$

$$\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} \quad (4.4)$$

Therefore, the final demand changes will influence industry's output for:

$$\Delta\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\Delta\boldsymbol{Y} \quad (4.5)$$

Table 4.1 Illustration of I-O table for 3 production sectors

Output allocation		Intermediate demands			Final demand	Supply	
Input structure		1	2	3		Import	Total output
Intermediate inputs	1	x_{11}	x_{12}	x_{13}	F_1	M_1	X_1
	2	x_{21}	x_{22}	x_{23}	F_2	M_2	X_2
	3	x_{31}	x_{32}	x_{33}	F_3	M_3	X_3
Primary input		V_1	V_2	V_3			
Total Input		X_1	X_2	X_3			

Similarly, output changes caused by price or other value-added changes could be estimated by using the following equation:

$$X_i = \sum_{j=1}^{n} X_{ij} + V_j = \sum_{j=1}^{n} r_{ij} X_j + V_j \quad (4.6)$$

in matrix terms:

$$\boldsymbol{X} = \boldsymbol{RX} + \boldsymbol{V} \quad (4.7)$$

$$\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{R})^{-1}\boldsymbol{V} \quad (4.8)$$

$$\Delta\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{R})^{-1}\Delta\boldsymbol{V} \quad (4.9)$$

where $\boldsymbol{X}$ is a vector of sectoral gross input; $\boldsymbol{R}$ is a matric of direct output or technical coefficients; $\boldsymbol{V}$ is a vector of value added, which consists of wages, salaries, profit, taxes, subsidy, etc.

The latest Indonesia's IO table consisted of economic transactions for 185 sectors and was published by BPS (2015) in 2010. The energy sector in the 2010 I-O table is represented by coal and lignite (sector 37), oil (sector 38), gas and geothermal (sector 39), and electricity (sector 145) sectors. The electricity sector is then disaggregated into specific following power plant types (and its abbreviation):

- Coal-based power plant (PLTU)
- Combined cycled gas turbine power plant (PLTGU)
- Open cycled gas turbine power plant (PLTG)
- Geothermal power plant (PLTP)
- Hydropower plant (PLTA)
- Small and Micro-hydro power plant (PLTM/H)
- Wind turbine power plant (PLTB)
- City waste to energy power plant (PLTSa)
- Biomass-based power plant (PLTBio)
- Solar power plant (PLTS)
- Oil-based power plant (PLTD)

Those power plant types refer to PLN's statistic format. Ideal disaggregation should use specific industry and energy mix in each region (Lindner et al., 2013), but it requires I-O tables from 33 provinces and other extensive data especially renewable energy investment data. On the other hand, Peters and Hertel (2016) compared four disaggregation methods and concluded that no method is dominant while consideration to select the method should be different for each case. Therefore, because of data availability, we adopt McDougall (2002) to use a reference table to disaggregate electricity sector in 2010 I-O table.

Ministry of Energy and Mineral Resources (MEMR), Agency of Fiscal Policy (BKF) and Central Bureau of Statistics (BPS) had collaborated to modify 2008 updating I-O table (BPS, 2009) by extending energy sectors to more specific sectors (Wargadalam, 2014). The modified table had been used to build a computable general equilibrium (CGE) model called Indonesia Clean Energy and Energy Conservation (INDOCEEC) model (Nugroho et al., 2016; Wargadalam et al., 2014). We use the modified 2008 table as a reference table to extend electricity sector in the 2010 I-O table. As a consequence, we assume that economic structure of electricity sector did not change during 2008 – 2010 and, indeed, we also hold this assumption for analysis until 2050.

After disaggregating the I-O table, for simplicity, we then aggregate sectors beyond electricity sector into two sectors, i.e. services and industry sectors. Based on the aggregated table, we then calculate its Leontief inverse matrix as in Table 4.2. In estimating the macroeconomic impact, ARISE multiply the matrix, stored in file "input output 6.txt", with the values of PV investment and interest payment to banking.

Table 4.2 Leontief inverse matrix of Indonesia’s IO table 2010

Sectors	1	2	145a	145b	145c	145d	145e	145f	145g	145h	145i	145j	145k	170
1	1.889418042	0.706517011	1.452235130	1.100994487	1.009720530	1.150158616	0.465114979	0.465114979	0.545630232	1.884013776	1.861579569	1.681922265	0.903502972	0.275988733
2	0.090927962	1.188609159	0.163083433	0.122157315	0.112167105	0.102448473	0.099881600	0.099881600	0.032662927	0.090991797	0.091256805	0.081855303	0.071287246	0.220743484
145a	0.008836675	0.009376697	2.431888981	0.005752633	0.005103191	0.005685395	0.002679094	0.002679094	0.029627985	0.008963740	0.009491215	0.008446721	0.004384705	0.008991382
145b	0.004316038	0.004579797	0.003590741	2.282042144	0.002492517	0.002776879	0.001308532	0.001308532	0.026900524	0.004447328	0.004992338	0.004390179	0.002141592	0.004391600
145c	0.001162903	0.001233970	0.000967481	0.000757044	2.393731978	0.000748196	0.000352568	0.000352568	0.063958876	0.001514137	0.002972180	0.002390160	0.000577026	0.001183262
145d	0.000679733	0.000721272	0.000565506	0.000442503	0.000392547	1.966576579	0.000206081	0.000206081	0.002287387	0.000689553	0.000730321	0.000649915	0.000337279	0.000691633
145e	0.001736708	0.001842841	0.001444860	0.001130589	0.001002951	0.001117374	2.317590509	0.000526533	0.017830742	0.001828560	0.002209857	0.001915696	0.000861744	0.001767113
145f	0.000011883	0.000012609	0.000009886	0.000007735	0.000006862	0.000007645	0.000003603	2.317070349	0.000003485	0.000011851	0.000011720	0.000010584	0.000005896	0.000012091
145g	0.000000001	0.000000001	0.000000001	0.000000001	0.000000001	0.000000001	0.000000000	0.000000000	1.000000000	0.000000001	0.000000001	0.000000001	0.000000000	0.000000001
145h	0.000000022	0.000000024	0.000000018	0.000000014	0.000000013	0.000000014	0.000000007	0.000000007	0.000000006	1.000000022	0.000000022	0.000000020	0.000000011	0.000000023
145i	0.000009208	0.000009771	0.000007661	0.000005994	0.000005318	0.000005924	0.000002792	0.000002792	0.000002700	0.000009183	1.000009082	0.000008202	0.000004569	0.000009369
145j	0.000000023	0.000000024	0.000000019	0.000000015	0.000000013	0.000000015	0.000000007	0.000000007	0.000000007	0.000000023	0.000000023	1.000000020	0.000000011	0.000000023
145k	0.000906790	0.000962206	0.000754407	0.000590316	0.000523673	0.000583417	0.000274920	0.000274920	0.019041284	0.001008949	0.001433031	0.001207409	1.459052724	0.000922666
170	0.013779062	0.021024921	0.022405197	0.045255033	0.015270299	0.017891573	0.019024219	0.019024219	0.004959486	0.013752177	0.013640572	0.012297290	0.008916370	1.005668068

Note: Industry (1), Services (2), PLTU (145a), PLTG – CCGT (145b), PLTG – OCGT (145c), PLTP (145d), PLTA (145e), PLTM/H (145f), PLTB (145g), PLTSa (145h), PLTBio (145i), PLTS (145j), PLTD (145k), Bank (170)

Section 5 Environmental Perspective: Life-Cycle Analysis (LCA)

LCA studies usually have a weakness on the assumption of total electricity production. Intermittent nature and technology reliability of renewable energy cause inaccurate estimation of capacity factor and, as a consequence, the electricity production could be overestimated. For Indonesia case as an example, many PV distributed to villagers were only used for 1 – 2 years while Peng et al. (2013) noted that previous LCA studies used the assumption of 20 – 30 year lifetime. Shorter actual operating life will increase emission per unit electricity supply. Therefore, stating impacts during construction in per capacity unit will provide more accurate comparisons of the impacts.

Environmental impacts of power plants during the construction and operational stages should be derived from studies in Table 5.1. Tahara et al. (1997) initially estimated environmental impacts per generated electricity, but all data and assumptions were clearly presented so that the impacts per constructed capacity could be calculated as in Table 5.1. Sullivan et al. (2010) analysed environmental impacts of four geothermal scenarios, and the analysis was started from well field development until the end of power plant operation year. Sullivan et al. (2010) also provided results of other studies for different power plant technologies.

Table 5.1 Data of environmental impact factors

Power plant technology	Construction (per MW capacity)					Emission in operating (kg CO_{2e}/ MWh)	Sources: Processed from following studies
	CO_{2eq} (kg)	Steel (ton)	Aluminium (ton)	Concrete (ton)	Energy (GJ)		
Coal	134456.4	62.2	0.6	178.3	450.0	915.9	Tahara et al. (1997)
Oil	101171.6	51.1	0.2	71.3	363.0	755.7	Tahara et al. (1997)
Gas - CCGT	57080.2	58.5	0.3	81.4	685.8	486.7	Sullivan et al. (2010)
Gas - OCGT	101440.0	51.1	0.2	71.3	363.0	563.0	Tahara et al. (1997)
Hydro	1554712.8	109.7	0.1	790.0	6,911.3	17.1	Tahara et al. (1997)
Geothermal	1423062.0	356.0	46.1	459.0	2059947.5	-	Sullivan et al. (2010)
Solar	4039116.9	103.5	4.0	50.0	491.6	148.0	Tahara et al. (1997)
Wind	696322.1	106.5	8.5	402.5	9750.0	0.9	Ghenai (2012)
Waste to energy	1499639.0	181.9		702.1	1631.1	347.2	Cherubini et al. (2009); Koroneos and Nanaki (2012); Meier (2002)
Biomass	139073.8	2076.0	1.3	159.0	1754.5	114.4	Sullivan et al. (2010)

Standard practice to hybrid I-O analysis and LCA is to multiply Equation 4.9 by matrix of diagonal environmental impact factors ($\boldsymbol{E_i}$) as following equation.

$$\boldsymbol{O_i} = \boldsymbol{E_i X} = \boldsymbol{E_i}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} \qquad (5.1)$$

where $\boldsymbol{O_i}$ is the total environmental impacts. Noori et al. (2015) extend the analysis by calculating total environmental burden ($\boldsymbol{R_i}$) by adding environmental impacts from inputs used for technology productions.

$$\boldsymbol{R_i} = \boldsymbol{E_i}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} + \boldsymbol{Q_i e_i} \qquad (5.2)$$

where $\boldsymbol{Q_i}$ is total input requirement and $\boldsymbol{e_i}$ is the environmental impact factors for the inputs.

The approach of Noori et al. (2015) could estimate all environmental impacts from the spare part manufacturing process until electricity production process, but requires intensive data of environmental impact factors in each economic sector. ARISE is limited by data availability that is the typical issue in developing countries. Therefore, here, our LCA scope is only to estimate direct environmental impacts which occur in power plants' construction and operation. The impacts are assessed by multiplying electricity production and new power plant capacity by environmental impact factors in Table 5.1.

Nevertheless, using data in Table 5.1 causes several shortcomings. First, the analysis ideally uses national data (tier 2) while the values in Table 5.1 are derived from other countries (tier 1). Second, even if national data is available, environmental impacts will be different for each site. Emissions of city waste to energy, for example, will be influenced by waste contents and distances from waste sources. Therefore, further research should use tier 2 or tier 3 data instead of data in Table 5.1.

Section 6 Structure of ARISE

ARISE is developed in NetLogo programming software and Figure 6.1 shows the interface of ARISE. ARISE is operated through three steps, i.e. data load, policy scenario setting and simulation process. While Step 1 and Step 3 must use the button provided, policy scenario can use the default values or user-defined values by using sliders provided. As in the left side of the interface in Figure 6.1, available policy scenario sliders are the capital subsidy, interest subsidy, loan period length, production tax credit (PTC), PTC period length, O&M incentives, tax holiday and feed-in tariff. Additionally, users can manually define investment cost, O&M costs, interest rate, and minimum down payment (DP). The analysis outputs will be displayed in a thematic map, two graphs showing environmental impacts and subsidy expenditure, and several output boxes showing I-O analysis result and cost calculation results. Data in the thematic map can be changed by using "GIS-code" chooser box and, for a while, the available options for the "GIS-code" chooser are the percentage of rural households using PV, the percentage of urban households using PV, and the percentage of rural household without electricity. Another chooser box is "ThresholdInvestment" providing options to choose average electricity expenditure or 10% household expenditure as a threshold for PV investment. We regard average electricity expenditure as a more reliable threshold because the values are average electricity expenditure by rural households in each province for buying PLN electricity. Therefore, as long as the PV cost is equal or lower than the average PLN electricity bill, then rural households without PLN electricity access most likely will use PV. More detailed mechanisms of ARISE are discussed in the following paragraphs.

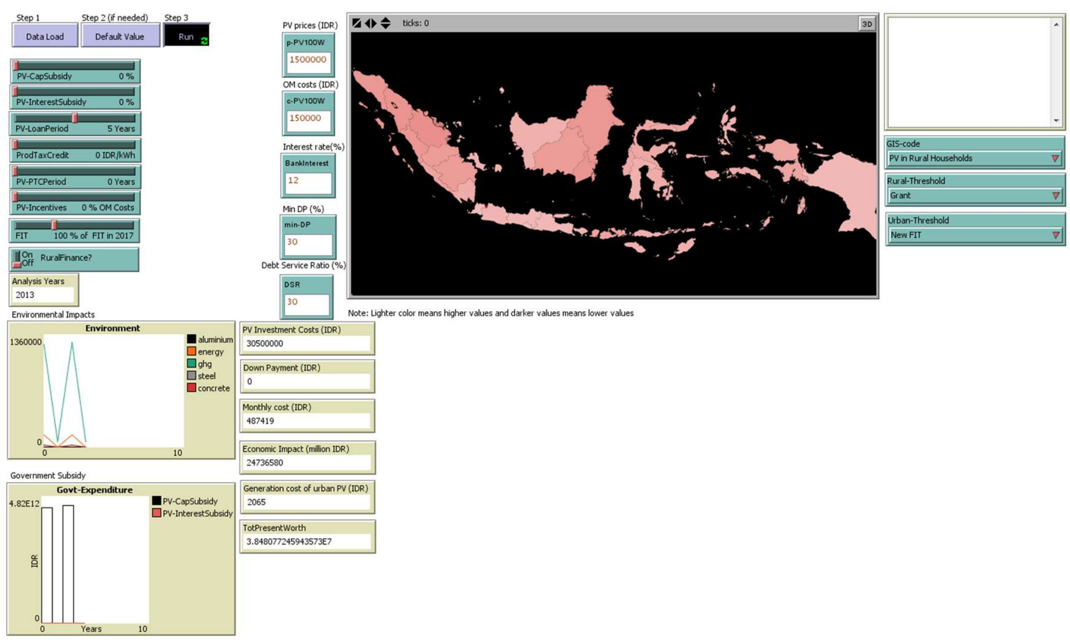

Figure 6.1 Interface of ARISE

Figure 6.2 describes the primary flowchart of ARISE. First, ARISE will open all data needed, i.e. initial values for variables and parameters, Leontief inverse matrix, and GIS files. By using the number of households and their income distributions in GIS files, agents of households are then created, and each household has properties of province, (urban-rural) area, electricity supply type, dwelling ownership, income, and PV ownership. Second, users should define the values for policy scenarios by using sliders or default button. The third step is the simulation process which in sequence estimates PV investments costs, investment decisions by rural and urban households, policy impacts, and growth of income and households.

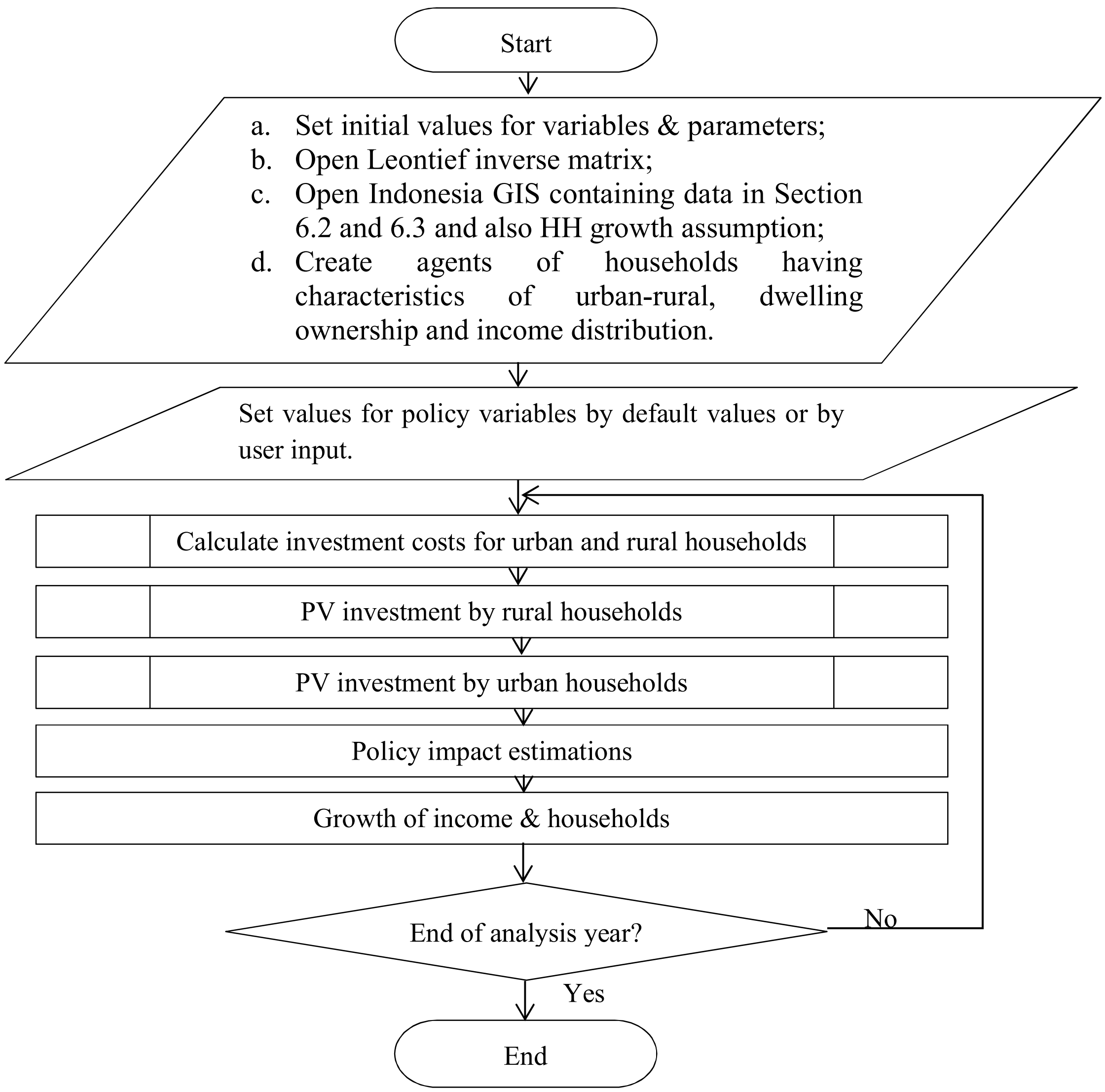

Figure 6.2 Main flowchart of ARISE

Rural and urban households have different PV investment costs because they have different purposes for PV investment. For their fundamental electricity supply, in Figure 6.3, rural households buy a 100 W PV module with cash payment:

$$PV\ capital\ cost = PV\ price - PV\ price\ subsidy \tag{6.1}$$

or, as in Figure 6.4, if loan finance is available, the rural households can have instalment payment with a down payment:

$$PV\ down\ payment = minimum\ down\ payment * \ PV\ capital\ costs \qquad (6.2)$$

$$Monthly\ payment\ = \left(Loan * \frac{Effective\ interest\ rate}{1-(1+Effectiv\ \ interest\ rate)^{-lo\ \ \ \ period}}\right) + OM\ Cost \qquad (6.3)$$

if $interest\ rate = 0$:

$$Monthly\ payment\ = \left(\frac{Loan}{loan\ period}\right) + OM\ Cost$$

where loan period is stated in month while loan and effective interest rate are derived from:

$$Loan = \ PV\ capital\ costs - PV\ capital\ subsidy - \ PV\ equity \qquad (6.4)$$

$$Effective\ interest\ rate = \frac{Bank\ interest\ rate - Interest\ subsidy}{12} \qquad (6.5)$$

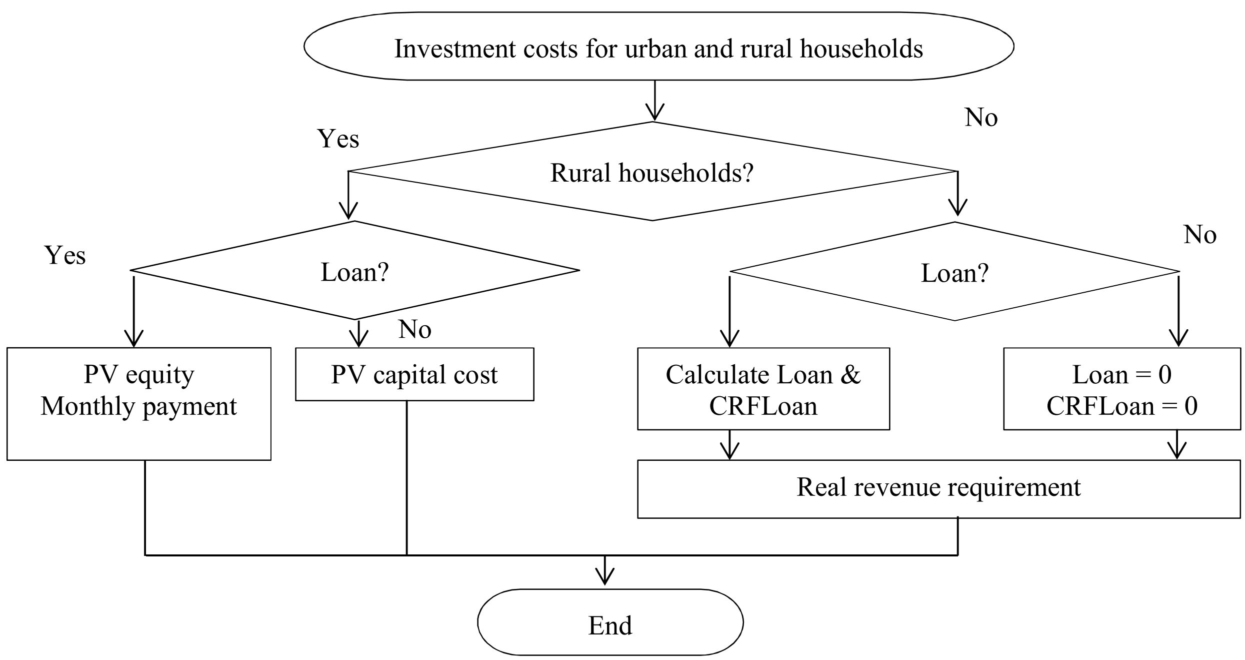

Figure 6.3 Sub flowcharts for calculation of investment costs for urban and rural households

$$Revenue\ requirement\ of\ energy = \frac{Annual\ revenue\ requirements}{Annual\ electricity\ productions} =$$

$$\frac{Total\ present\ worth * (\ Cost\ of\ Equity * \frac{(1+\ Cost\ of\ Equity)^{Economic\ life}}{(1+\ Cost\ of\ Equity)^{Economic\ life}-1})}{Capacity * CF * 24 * 365} \qquad (6.6)$$

where capacity is for power plant capacity (kW), CF is for capacity factor (%), cost of equity is for the rate of return on the equity portion of the investment and is assumed at 15%, and economic life is a lifetime of the equipment. The total present worth is defined as:

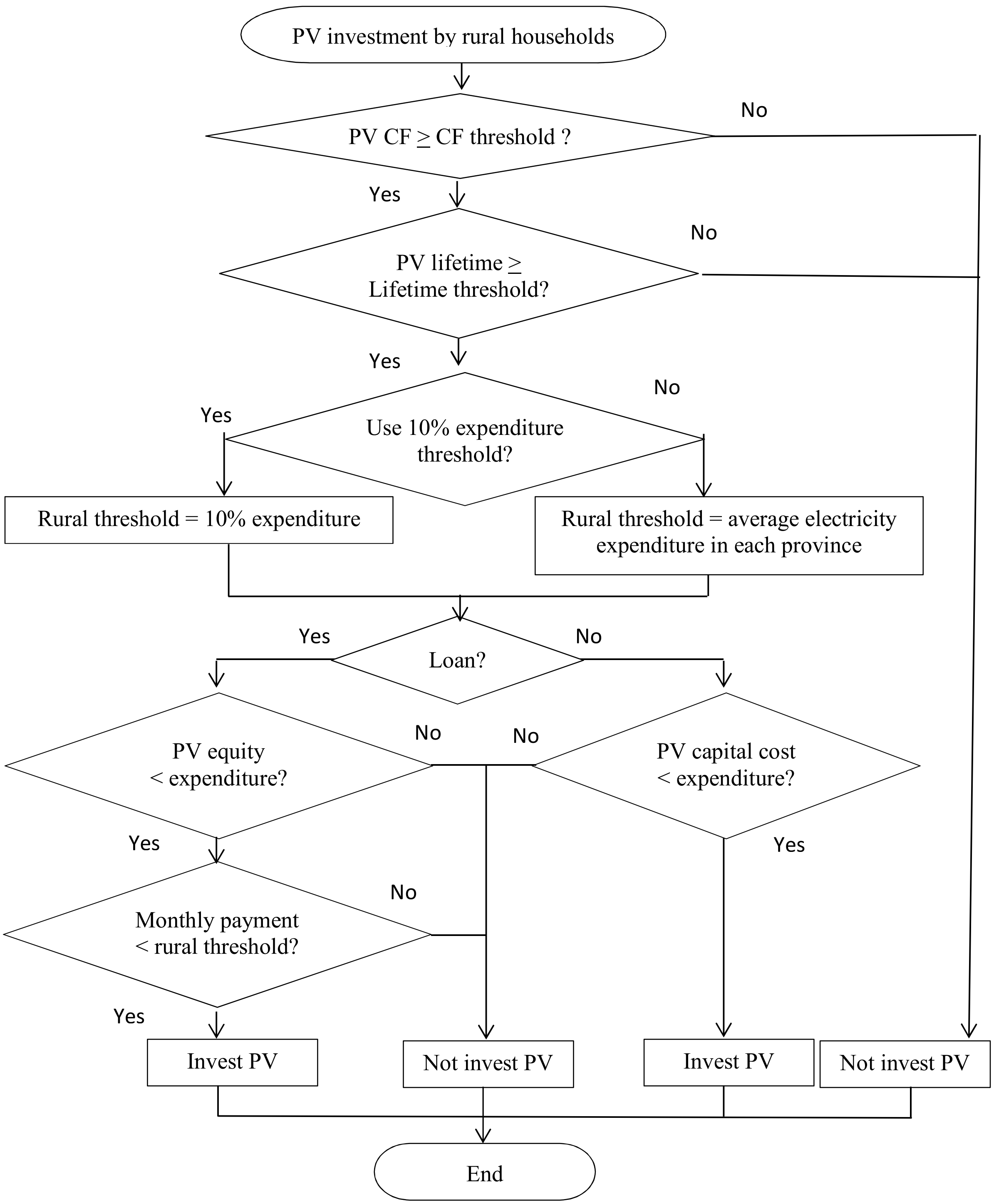

Figure 6.4 Sub flowcharts for PV investment decision by rural households

$$Total\ present\ worth = \sum_t^{Economic\ Life}(Equity\ recovery_t + Debt\ recovery_t + Annual\ OM\ Costs_t + Taxes_t + Debt\ reserves_t - Incentives_t - Interest\ on\ debt\ reserves_t) * (1 + Cost\ of\ Equity)^{-t} \quad (6.7)$$

which is derived from:

a. equity recovery which is uniform annual revenue to earn a stipulated rate of return on equity:

$$Equity\ recovery_t = (Total\ equity * Cost\ of\ Equity) * \frac{(1+ Cost\ of\ Equity)^{Economic\ life}}{(1+ Cost\ of\ Equity)^{Economic\ life} - 1}) \quad (6.8)$$

where total equity is obtained by using Equation 6.1 but stated in IDR/ Wp instead of IDR/ 100 Wp.

b. debt recovery which is the fix annual debt payment:

$$Debt\ recovery_t = Loan * \frac{(1+ Loan\ interests)^{Loan\ period}}{(1+ Loan\ interests)^{Loan\ period} - 1}) \quad (6.9)$$

where loan period is stated in years;

c. annual O&M costs which consist of annual fix O&M costs and periodic inverter replacement costs:

$$Annual\ OM\ costs_t = (FixOMCost + Inverter\ costs_t) * (1 + Escalation)^{t-1} \quad (6.10)$$

d. debt reserve which is guaranteed fund placed in the reserve account to warrant debt repayment. Debt reserve is assumed to be equal to debt recovery and will be returned at the end of loan period. Hence, debt reserve gains interest annually.

e. incentive which is a parameter for general incentive that may reduce O&M costs; and

f. taxes for the investment and operation of the PV:

$$Taxes_t = \left(\frac{Tax\ rates}{1 - Tax\ rates}\right) * (Equity\ principal\ paid_t + Debt\ principal\ paid_t + Equity\ interest_t + Debt\ reserves_t - Depreciation_t - Tax\ Credit_t) \quad (6.11)$$

where:

$$Equity\ principal\ paid_t = Equity\ recovery_t - Equity\ interest_t \quad (6.12)$$

$$Equity\ interest_t = Cost\ of\ equity * Equity\ principal\ remaining_{t-1} \quad (6.13)$$

$$Equity\ principal\ remaining_t = Equity\ principal\ remaining_{t-1} - Equity\ principal\ paid_t \quad (6.14)$$

$$Debt\ principal\ paid_t = Debt\ recovery_t - (Loan\ interest * Debt\ principal\ remaining_{t-1}) \quad (6.15)$$

$$Debt\ principal\ remaining_t = Debt\ principal\ remaining_{t-1} - Debt\ principal\ paid_t$$

(6.16)

$$Depreciation_t = \frac{1}{Economic\ life} * Total\ costs \qquad (6.17)$$

$$Tax\ Credit = Production\ tax\ credit\ rate * Annual\ electricity\ productions \qquad (6.18)$$

Real total presented worth is calculated by adding inflation effect:

$$Real\ total\ present\ worth = Total\ present\ worth * \left(\frac{1+cost\ of\ equity}{1+inflatio} - 1\right) * \left(\frac{\left(1+\left(\frac{1+cost\ of\ equity}{1+inflatio}\right)\right)^{economic\ life}}{\left(1+\left(\frac{1+cost\ of\ equity}{1+inflation}\right)\right)^{economic\ life} - 1}\right) \qquad (6.19)$$

As in Figure 6.5, urban households at first will evaluate whether renewable energy –based electricity tariff is higher than the estimated revenue requirement of energy. If the tariff is higher then the urban households need at least 30% of their monthly expenditure, representing income, to be equal to required equity for PV investment. Here, we assume that households do not have savings to pay the minimum equity needed by the bank and they have profit maximum behaviour. If the needed equity is zero, the urban households will spend 30% of their expenditures for PV investment but the maximum capacity invested is constrained by incurred monthly O&M costs, which equates to revenue requirement. Otherwise, the investment of new PV capacity depends on expenditure level and required equity costs.

After the number of PV investment has been simulated, the next step is to estimate economic impacts. Each year, capital cost and OM costs are calculated using these subsidies and treated as a final demand for government expenditure in IO analysis. Additionally, capital and interest subsidies paid by the government are also calculated by using following equations:

$$Capital\ subsidy_t = PV\ investment_t * PV\ subsidy\ unit \qquad (6.20)$$

$$Interest\ subsidy_t = PV\ investment_t * (Installment\ without\ subsidy - Installment\ with\ subsidy) \qquad (6.21)$$

On the other hand, environmental impacts are estimated in manufacturing and operational stages:

$$Manufacturing\ impact_{it} = New\ PV\ capacity_t * Environmental\ impact\ factor_i \qquad (6.22)$$

$$Operational\ impact_t = PV\ annual\ electricity\ generation_t * GHG\ emission\ factor$$

(6.23)

where i is for aluminium, energy, GHG emission, steel and concrete.

The last procedure in Figure 6.2 is to estimate growths of income and household number for next year analysis. The income of each household type is assumed to grow as much as the mean of income growth in 2010-2011 (BPS, 2010, 2011):

$$Income_{i,t+1} = Income_{i,t} * (1 + mean\ income\ growth_i) \qquad (6.24)$$

where i is the household type.

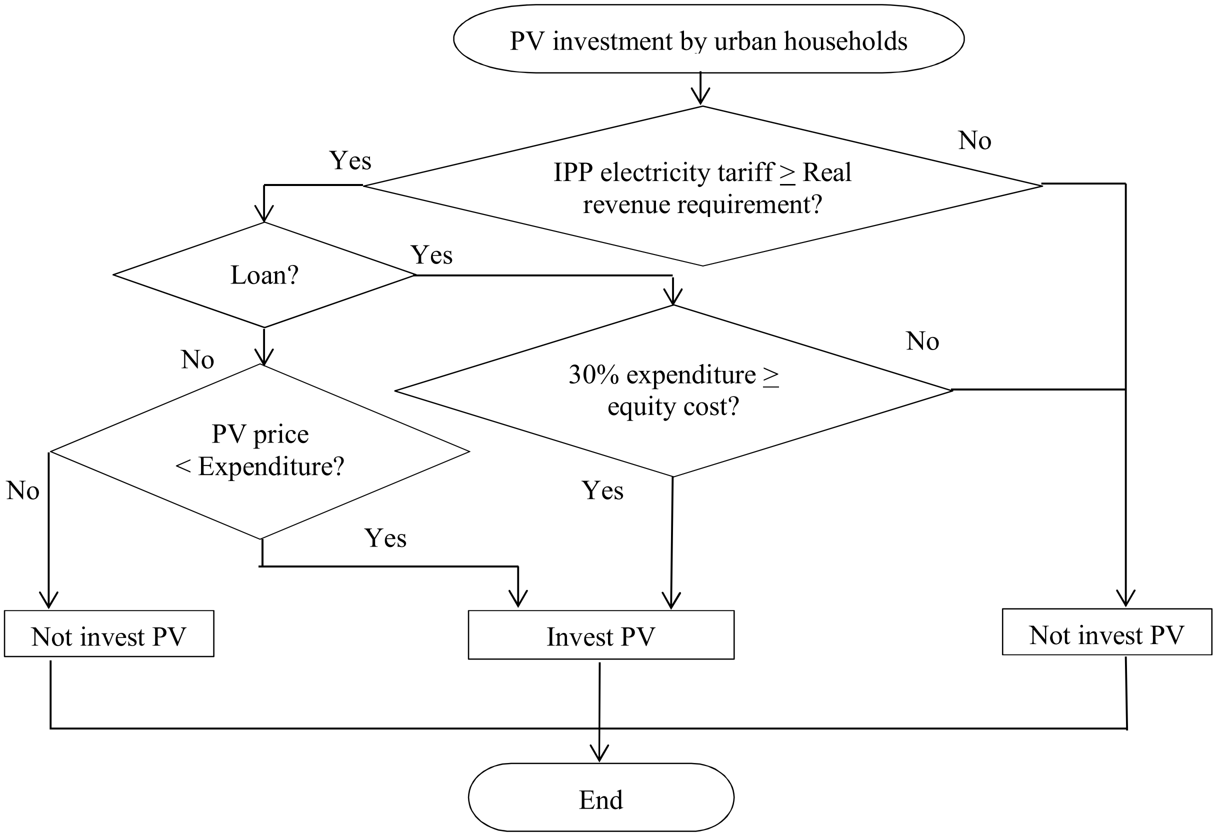

Figure 6.5 Sub flowcharts for PV investment decision by urban households

By contrast, differences of data in Susenas 2010 and Susenas 2011 may produce bias result of household growth since Susenas is the sample of the total population. Meanwhile, the only available data is total household growths in 2002 - 2014 that are then analysed to obtain annual growth rates as in Figure 6.6. The growth rates do not have trend so that the random household growth is used in ARISE by referring minimum, maximum, average, and standard deviation values of the growths during 2002 – 2014.

Moreover, the growth should not be the same in urban and rural areas. Figure 6.7 shows that urbanisation rate in the last 10 years is continuously declining thus is interpolated by using the previous steady changes of urbanisation rate in 2011 – 2012 and 2012 -2013. The interpolation result of urbanisation rate in Figure 6.7 is used to estimate the percentages of the urban and rural population. The randomised growth of household is then multiplied by the population share:

$$Household_{urban,i,t+1} = Household_{urban,i,t} * (1 + household\ growth) * urban\ share_t \quad (6.25)$$

$$Household_{rural,i,t+1} = Household_{rural,i,t} * (1 + household\ growth) * rural\ share_t \quad (6.26)$$

where i is household types, e.g. household with PLN access and house owner.

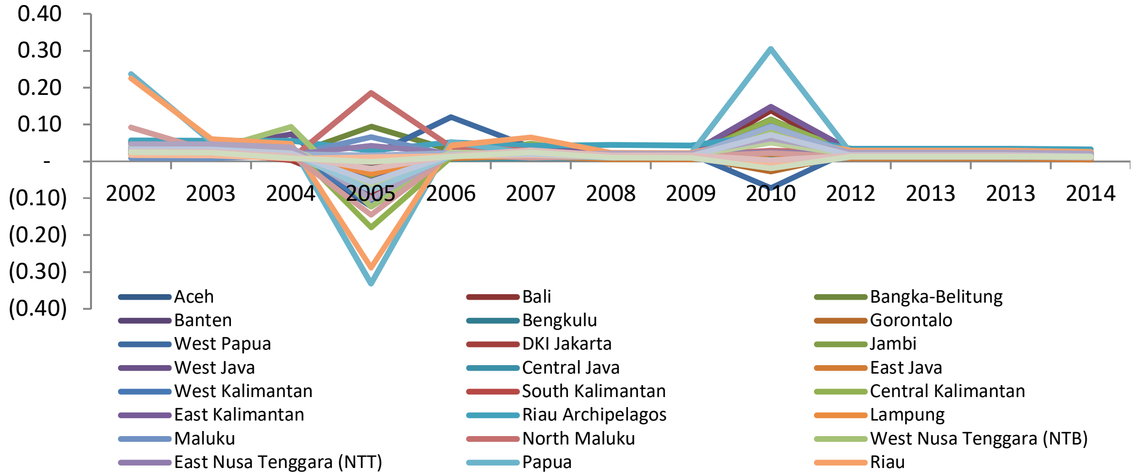

Figure 6.6 Growth rates of household numbers in 2002 – 2014

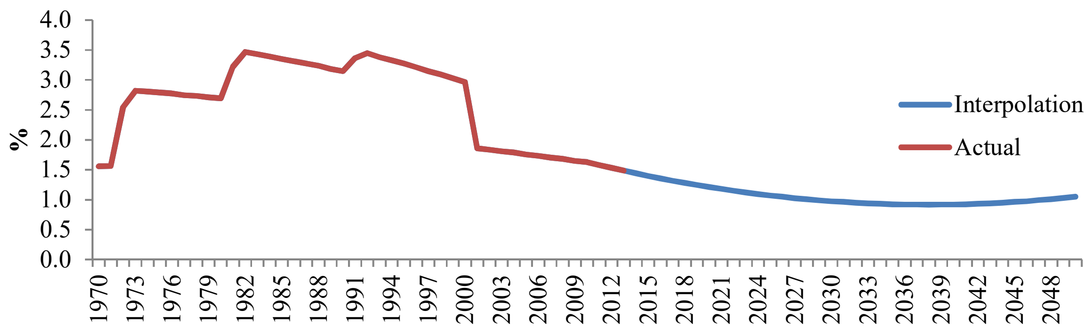

Figure 6.7 Assumptions for growth rate of urbanisation

Section 7 Validation of ARISE

Before using ARISE for policy simulation, ARISE algorithm should be validated by comparing ARISE results and manual calculations conducted in Microsoft Excel. The main concerns for PV investments are the number of households, PV investment costs, number of PV investments, economic impacts, and environmental impacts. The current version of ARISE saves simulation results into 3 files for validation and analysis purposes:

- Householdchecks.csv
  This file is for validation purpose. The file contains the number of household agent (in 1000 unit) who represents the actual number of households in each province.
- Number of PV.csv
  This file contains the number of household agents and the number of PV investing household agents at the end year of analysis.
- Policy simulation.csv
  This file contains following simulation results/ parameters:

years	:	Analysis year
PV	:	PV final demand (million IDR)
ruralPVinHH	:	Accumulated number of PV 100 Wp in rural area (unit PV)
yearlyPVinRural	:	Annual PV 100 Wp investment in rural area (unit PV)
urbanPVinHH	:	Accumulated number of PV in urban area (unit PV)
yearlyPVinUrban	:	Annual PV investment in urban area (unit PV)
economicImpact	:	Economic impact (million IDR)
ghgPV_ops	:	GHG operational (kg CO2eq)
ghgPV_con	:	GHG construction (kg CO2eq)
alumPV	:	Aluminium (ton)
enerPV	:	Energy (GJ)
steelPV	:	Steel (ton)
concPV	:	Concrete (ton)
PV-LoanPeriod	:	Loan Period (years)
PV-CapSubsidy-R	:	Rural Capital subsidy (%)
PV-CapSubsidy	:	Urban Capital subsidy (%)
PV-InterestSubsidy	:	Interest Subsidy (%)
TcapSubsidy	:	Annual capital subsidy (IDR)
TinterestSubsidy	:	Annual interest subsidy (IDR)
SupplyCost-PV	:	Transaction values of PV-based electricity supply (million IDR)
PVCityCost	:	Levelised cost of PV-based electricity production – urban households (IDR/ kWh)
PVcapCost	:	PV capital cost or minimum PV equity after capital subsidy and (IDR)
m-payment	:	Monthly loan payment – urban households
m-payment-R	:	Monthly loan payment – rural households
p-PV100W	:	Price of PV 100Wp (IDR)
PV-Price	:	Price of PV (IDR/ Wp)

PV-Capacity	:	Capacity of PV for urban households (Wp)
ruralPV-capacity	:	Capacity of PV for rural households (Wp)
PV-OMCost-R	:	Operational and maintenance (OM) cost of PV for rural households (IDR)
AnnualCost	:	OM cost of PV for urban households (IDR/ kWh)
InverterCost	:	Total transaction values of inverter replacement (IDR)
InverterReplacementUnit	:	Number of inverters that should be replaced in each year (unit)
PV-InverterPrice	:	Price of PV inverter (IDR/ unit)
rural-interest-subsidy	:	Values of interest subsidy given to rural households (IDR)
urban-interest-subsidy	:	Values of interest subsidy given to urban households (IDR)
FIT	:	Previous Feed-in Tariff (IDR/kWh)
PV-CF	:	Capacity factor of PV (%)
InterestPayment	:	Loan interest paid by households (IDR)
PVInvestCost_rural	:	Total values of PV investments in rural area (million IDR)
PVInvestCost_urban	:	Total values of PV investments in urban area (million IDR)
PVOMCost_rural	:	Total values of PV OM costs in rural area (million IDR)
PVOMCost_urban	:	Total values of PV OM costs in urban area (million IDR)

7.1 Number of Households

Due to the limitation of computer processing ability, the actual number of households must be downscaled to 1,000 units, meaning that 1,000 real households are represented by a household agent in ARISE. As an agent cannot be a fraction, ARISE suffers the bias from the rounding of division results. The bias may increase over the years due to household growth and, thus should be quantified by comparing the number of households in ARISE and manual calculation. The comparison analysis is conducted at the scaled number to check the validity of algorithm in ARISE and the actual number to quantify the bias.

Table 7.1 and 7.2 clarify the accuracy of ARISE's algorithms. As expected, ARISE could accurately divide the actual household number by 1,000 units, indicated by exact results of manual calculation and ARISE calculation in Table 7.1. Moreover, by using random household growths produced by ARISE, manual calculation produces exact number of households in 2050 as in Table 7.2. However, though ARISE algorithm has been correctly specified, bias from division rounding is inevitable.

For households in number 2010, multiplying ARISE results by 1,000 unit produces 0.31% error for the total household number. The highest error occurs in urban households without electricity and non-owner of a house because of their lowest number. This household type in several provinces has values lower than 1,000 and, consequently, ARISE converts the values to zero. Over the years, the error is growing along with household growth estimation. The error for urban households without electricity and non-owner of a house rises from 22.1% in 2010 to 101.4% in 2050. Though this is not ideal estimation, we ignore the problem since this household type is not the primary concerns. This household type will surely register as PLN's subscriber first instead of investing in renewable energy. Urban households with PLN access - owner of a dwelling and also rural households without electricity access - are the primary concerns in ARISE and have errors in 2010 for 0.08% and 0.54% respectively. In 2050, their estimated number is also relatively low at 0.04% and 1.32% respectively while the total error is only 1.15%.

Table 7.1 Validation of household number in 2010

Household types	In 1000 household unit			In a household unit		
	Manual	ARISE	Error (%)	Manual	ARISE	Error (%)
Urban with PLN access and owner of house	19,899	19,899	0.00	19,915,425	19,899,000	0.08
Urban with PLN access and non-owner of house	9,225	9,225	0.00	9,241,745	9,225,000	0.18
Urban without PLN access and owner of house	462	462	0.00	476,075	462,000	3.05
Urban without PLN access and non-owner of house	245	245	0.00	261,881	245,000	6.89
Urban without electricity and owner of house	253	253	0.00	266,057	253,000	5.16
Urban without electricity and non-owner of house	78	78	0.00	95,260	78,000	22.13
Rural with PLN access and owner of house	22,357	22,357	0.00	22,372,704	22,357,000	0.07
Rural with PLN access and non-owner of house	2,785	2,785	0.00	2,799,954	2,785,000	0.54
Rural without PLN access and owner of house	1,906	1,906	0.00	1,922,213	1,906,000	0.85
Rural without PLN access and non-owner of house	477	477	0.00	493,347	477,000	3.43
Rural without electricity and owner of house	2,922	2,922	0.00	2,937,911	2,922,000	0.54
Rural without electricity and non-owner of house	367	367	0.00	381,869	367,000	4.05
Total	60,976	60,976	0.00	61,164,441	60,976,000	0.31

Table 7.2 Validation of household number growth in 2050

Household types	In 1000 household unit			In a household unit		
	Manual	ARISE	Error (%)	Manual	ARISE	Error (%)
Urban with PLN access and owner of house	28,516	28,516	0.00	28,527,147	28,516,000	0.04
Urban with PLN access and non-owner of house	13,794	13,794	0.00	13,863,917	13,794,000	0.51
Urban without PLN access and owner of house	659	659	0.00	780,761	659,000	18.48
Urban without PLN access and non-owner of house	356	356	0.00	450,062	356,000	26.42
Urban without electricity and owner of house	314	314	0.00	445,632	314,000	41.92
Urban without electricity and non-owner of house	78	78	0.00	157,107	78,000	101.42
Rural with PLN access and owner of house	26,219	26,219	0.00	26,243,092	26,219,000	0.09
Rural with PLN access and non-owner of house	3,311	3,311	0.00	3,400,468	3,311,000	2.70
Rural without PLN access and owner of house	2,428	2,428	0.00	2,496,051	2,428,000	2.80
Rural without PLN access and non-owner of house	544	544	0.00	637,202	544,000	17.13
Rural without electricity and owner of house	3,930	3,930	0.00	3,981,950	3,930,000	1.32
Rural without electricity and non-owner of house	398	398	0.00	493,497	398,000	23.99
Total	80,547	80,547	0.00	81,476,886	80,547,000	1.15

7.2 PV Investment Costs

Algorithms for PV investment costs are validated by comparing ARISE results and manual calculations for Equation 6.1 – 6.19. The validation of PV investment costs for rural households uses a combination of extreme and moderate values of inputs as in Table 7.3. From 2,187 input combination possibilities, Table 7.4 shows 12 input combinations with the conclusion that calculation algorithm of PV has been correctly specified. Output indicators of capital cost, monthly payment with and without interest subsidy, loan amount, interest subsidy paid by the government and effective interest rate are inspected. As in Table 7.4, manual calculations by using spreadsheets to these indicators are similar to ARISE outputs.

The calculation of PV investment cost for urban households is more complicated than calculation for investment cost in rural area. 12 inputs in Table 7.5 influence the costs and their minimum-default-maximum values have more than 31 million combination possibilities. For the inspected output indicators, constant revenue requirement, equity and annual electricity production are analysed with results in Table 7.6. Indicated by all zero differences, 10 input combinations ranging from low to high extremes show no errors in the algorithm of PV investment costs for urban people.

7.3 Number of PV Investments and Environmental Impacts

Validating number of PV investments cannot be conducted manually since the investment is influenced by households' income randomly generated by ARISE. However, the validation could be performed at two extreme output values, i.e. zero investment and 100% investment, by comparing the number of agents and the number of investment. Under zero investment scenario, all prices and cost are set to very high, i.e. 100 million IDR. As ARISE results in Table 7.7, from 2,999 agents of rural households without electricity access – house owner and 19,899 agents of urban household with electricity access – house owner, none of them invests in PV so that investment rate reaches 0%. In 100% investment scenario, all prices and cost are set to zero while FIT increases to 1,000% of current values, causing all agents to invest in PV.

Simulated numbers of investment are then used to validate algorithm of environmental impact analysis. In the construction stage, environmental impacts are calculated by multiplying the number of investment with capacity and environmental factors. Similarly, Equation 6.23 specifies greenhouse gases (GHG) emission in operational stages as a multiplication of emission factor and annual electricity production, derived from multiplication of numbers of investment, capacity, operational hours, and capacity factor. The validation results in Table 7.7 show that ARISE and manual calculation of environmental impacts have similar outputs.

7.4 Economic Impacts

The number of investment simulated by ARISE is also used for validation of economic impact. However, instead of using two extreme scenarios only, two other moderate scenarios are used for the validation. At scenario 4, i.e. zero investment scenario, ARISE and manual calculation show similar conclusion, i.e. no economic impact is shown as in Table 7.8. However, 100% investment scenario in scenario 2 has different macroeconomic impact values, that ARISE produces 249.8 million IDR lower than manual calculations. The difference is caused by limited digit number of Leontief inverse matrix in the ARISE model, while digit number in spreadsheet is unlimited. Consequently, a higher amount of investment will produce higher errors of macroeconomic analysis through the maximum error is relatively small compared to the total macroeconomic impact. We clarify this issue by using default values and 12% interest subsidy scenarios, and as a result, both scenarios have errors less than 0.001 million IDR.

Table 7.3 Input values for validation of PV investment costs for rural households

Variables	Minimum	Moderate	Maximum
PV 100 Wp price (IDR)	0	2,484,000	10,000,000
Minimum down payment (%)	0	30	100
PV capital subsidy (%)	0	50	100
PV interest subsidy (%)	0	12	100
PV loan period (years)	0	5	10
Bank interest (%/years)	0	12	100

Table 7.4 Validation of PV investment costs by rural households

Scenarios	0	1	2	3	4	5	6	7	8	9	10	11	12
Inputs													
PV 100 Wp price (IDR)	2,484,000	0	2,484,000	2,484,000	2,484,000	2,484,000	2,484,000	10,000,000	0	2,484,000	2,484,000	2,484,000	2,484,000
Minimum down payment (%)	30	0	100	30	30	30	30	30	30	30	0	0	0
PV capital subsidy (%)	0	0	0	100	0	0	0	0	0	50	0	30	30
PV interest subsidy (%)	0	0	0	0	12	0	0	0	0	7	0	0	3
PV loan period (years)	5	0	0	5	5	10	0	5	5	5	5	5	5
Bank interest (%/years)	12	0	0	12	12	12	12	12	12	12	12	12	12
OM cost (IDR/tahun)	250,000	-	250,000	250,000	250,000	250,000	250,000	-	12,000,000	250,000	250,000	250,000	250,000
Manual calculation													
PV Capital cost (IDR)	745,200	-	2,484,000	-	745,200	745,200	2,484,000	3,000,000	-	372,600	-	-	-
Monthly payment with subsidy (IDR)	59,512	-	20,833	20,833	49,813	45,780	20,833	155,711	1,000,000	37,240	76,089	59,512	56,928
Monthly payment without subsidy (IDR)	59,512	-	20,833	20,833	59,512	45,780	20,833	155,711	1,000,000	40,173	76,089	59,512	59,512
Loan amount (IDR)	1,738,800	-	-	-	1,738,800	1,738,800	-	7,000,000	-	869,400	2,484,000	1,738,800	1,738,800
Subsidy payment (IDR)	-	-	-	-	581,919	-	-	-	-	175,960	-	-	155,041
Effective interest rate (%)	0.01	-	-	0.01	-	0.01	-	0.01	0.01	0.00	0.01	0.01	0.01
ARISE result													
PV Capital cost (IDR)	745,200	-	2,484,000	-	745,200	745,200	2,484,000	3,000,000	-	372,600	-	-	-
Monthly payment with subsidy (IDR)	59,512	-	20,833	20,833	49,813	45,780	20,833	155,711	1,000,000	37,240	76,089	59,512	56,928

Monthly payment without subsidy (IDR)	59,512	-	20,833	20,833	59,512	45,780	20,833	155,711	1,000,000	40,173	76,089	59,512	59,512
Loan amount (IDR)	1,738,800	-	-	-	1,738,800	1,738,800	-	7,000,000	-	869,400	2,484,000	1,738,800	1,738,800
Subsidy payment (IDR)	-	-	-	-	581,919	-	-	-	-	175,960	-	-	155,041
Effective interest rate (%)	0.01	-	-	0.01	-	0.01	-	0.01	0.01	0.00	0.01	0.01	0.01
Differences													
PV Capital cost (IDR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly payment with subsidy (IDR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monthly payment without subsidy (IDR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loan amount (IDR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Subsidy payment (IDR)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Effective interest rate (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note on the scenario name: (1) Default; (2) Technology is unavailable; (3) No financing ; (4) 100% capital subsidy; (5) 100% interest subsidy; (6) 10 year loan period; (7) Zero year loan period; (8) High technology price but zero maintenance cost; (9) Low quality technology grant but high maintenance costs; (10) Combination of capital & interest subsidies; (11) No down payment; and (12) No down payment and capital subsidy 30%.

Table 7.5 Input values for validation of PV investment costs for urban households

Items	Minimum	Default	Maximum
PV Price (IDR/Wp)	0	24,840	1,000,000
OM cost (IDR/Wp/year)	0	384.24	100,000
Inverter lifetime (years)	0	10	20
Debt ratio (%)	0	70	100
Inverter price (IDR)	0	13,000,000	100,000,000
Capacity (Wp)	0	1,500	100,000
Cost of equity (%/years)	0	15	100
Bank interest (%/years)	0	12	50
Capacity factor (%/years)	0	16	200
Income tax (%)	0	10	150
PV loan period (years)	0	5	20
PV lifetime (years)	0	20	10
Debt reserves (% of yearly loan installment)	0	100	300
Inflation (%/year)	0	5.1	100
Interest rate on debt reserves (%)	0	1.3	100
Escalation (%/year)	0	1.0	100
PV capital subsidy (%)	0	0	100
PV interest subsidy (%)	0	0	100
Production tax credit (PTC) (IDR/kWh)	0	0	10,000
PTC period (years)	0	0	20
Other incentives (% of annual OM costs)	0	0	100
Tax holidays period (years)	0	0	10

Table 7.6 Validation of PV investment costs by urban households

Scenarios	0	1	2	3	4	5	6	7	8	9	10
Inputs											
PV Price (IDR/Wp)	24,840	0	1,000,000	24,840	24,840	24,840	24,840	1,000,000	10,000	24,840	24,840
OM cost (IDR/Wp/year)	384.24	-	100,000	384.24	384.24	384.24	384.24	-	500.00	384.24	384.24
Inverter lifetime (years)	10	0	20	10	10	10	10	20	2	10	10
Debt ratio (%)	70	0	100	70	70	70	0	70	70	70	100
Inverter price (IDR)	13,000,000	0	100,000,000	13,000,000	13,000,000	13,000,000	13,000,000	13,000,000	7,000,000	13,000,000	13,000,000
Capacity (Wp)	1,500	0	100,000	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Cost of equity (%/years)	15	0	100	15	15	15	15	15	15	15	15
Bank interest (%/years)	12	0	50	12	12	12	12	12	12	12	12
Capacity factor (%/years)	16	0	200	16	16	16	16	50	5	16	16
Income tax (%)	10	0	150	10	10	10	10	10	10	10	10
PV loan period (years)	5	0	20	5	5	10	0	5	5	5	5
PV lifetime (years)	20	0	10	20	20	20	20	20	10	20	20
Debt reserves (% of yearly loan installment)	100	0	300	100	100	100	100	100	100	100	100
Inflation (%/year)	5.1	0	100	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Interest rate on debt reserves (%)	1.3	0	100	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Escalation (%/year)	1.0	0	100	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PV capital subsidy (%)	0	0	100	100	0	0	0	0	0	30	0
PV interest subsidy (%)	0	0	100	0	12	0	0	0	0	3	0
Production tax credit (PTC) (IDR/kWh)	0	0	10,000	0	0	0	0	0	0	0	0
PTC period (years)	0	0	20	0	0	0	0	0	0	0	0
Other incentives (% of annual OM costs)	0	0	100	0	0	0	0	0	0	0	0
Tax holidays period (years)	0	0	10	0	0	0	0	0	0	0	0
Manual calculation											
Constant revenue requirement (IDR/kWh)	3,268.5	0	-	377.0	1,182	3,162	3,280	27,855	10,055	2,301.8	3,263.4

PV equity (IDR)	15,078,000	0	-	-	15,078,000	15,078,000	50,260,000	453,900,000	6,600,000	10,554,600	-
Electricity production (kWh/ year)	2,102.4	0	1,752,000	2,102	2,102	2,102	2,102	6,570	657	2,102.4	2,102.4
ARISE result											
Constant revenue requirement (IDR/kWh)	3,268.5	-	-	377.0	1,182.3	3,161.5	3,280.5	27,854.8	10,055.1	2,301.8	3,263.4
PV equity (IDR)	15,078,000	-	-	-	15,078,000	15,078,000	50,260,000	453,900,000	6,600,000	10,554,600	-
Electricity production (kWh/ year)	2,102.4	-	1,752,000	2,102.4	2,102.4	2,102.4	2,102.4	6,570.0	657.0	2,102.4	2,102.4
Differences											
Constant revenue requirement (IDR/kWh)	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV equity (IDR)	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity production (kWh/ year)	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note on the scenario name: (1) Default; (2) Technology is unavailable; (3) No financing ; (4) 100% capital subsidy; (5) 100% interest subsidy; (6) 10 year loan period; (7) Zero year loan period; (8) High technology price but zero maintenance cost; (9) Low quality technology grant but high maintenance costs; and (10) Combination of capital & interest subsidies.

Table 7.7 Validation of PV investment decisions and environmental impacts in 2010

Scenario*	Rural households without electricity access - house owner		Urban households with PLN access- house owner	
	No investment	100% investment	No investment	100% investment
Input				
PV Price (IDR/ 100 Wp)	100,000,000	0	100,000,000	0
OM costs (IDR/year)	100,000,000	0	100,000,000	0
PV inverter price (IDR)			100,000,000	0
FIT (% of 2017 tariff)			100	1000
Manual calculation				
Number of households (in 1,000 unit)	2,922	2,922	19,899	19,899
Greenhouse gases - operational (kg CO2eq)	0	60,613,033.0	0	6,191,677,324.8
Greenhouse gases - construction (kg CO2eq)	0	1,180,229,958.2	0	120,561,580,789.7
Aluminium (ton)	0	1,168.8	0	119,394.0
Energy (GJ)	0	143,639.7	0	14,672,925.6
Steel (ton)	0	30,242.7	0	3,089,319.8
Concrete (ton)	0	14,610.0	0	1,492,425.0
ARISE result				
Number of investment (in 1,000 unit)	0	2,922	0	19,899
Investment rate (%)	0	100	0	100
Greenhouse gases - operational (kg CO2eq)	0	60,613,033.0	0	6,191,677,324.8
Greenhouse gases - construction (kg CO2eq)	0	1,180,229,958.2	0	120,561,580,790
Aluminium (ton)	0	1,168.8	0	119,394
Energy (GJ)	0	143,639.7	0	14,672,926
Steel (ton)	0	30,242.7	0	3,089,320
Concrete (ton)	0	14,610.0	0	1,492,425
Differences				
Greenhouse gases - operational (kg CO2eq)	0	0	0	0
Greenhouse gases - construction (kg CO2eq)	0	0	0	0
Aluminium (ton)	0	0	0	0

Energy (GJ)	0	0	0	0
Steel (ton)	0	0	0	0
Concrete (ton)	0	0	0	0
Greenhouse gases - operational (kg CO2eq)	0	0	0	0

* Conducted at other default values

Table 7.8 Validation of macroeconomic impacts in 2010

Scenario	Default	100% capital subsidy	12% interest subsidy	Price IDR 10 million per 100Wp & no loan
	1	2	3	4
New final demand of PV (IDR million) in ARISE	4,057,256.00	269,654,544,114,399,000.00	5,096,176.00	-
Interest payment (IDR million) in ARISE	309,645.50	-	388,934.78	
Economic impact from ARISE (IDR million) in ARISE	11,811,186.51	753,709,734,823,249,000.00	14,835,614.32	-
Economic impact from manual calculation (IDR million)	11,811,186.51	753,709,734,823,247,000.00	14,835,614.3	-
Differences (IDR million)	- 0	2,176	- 0	-

Note on the scenario name: (1) Default values; (2) 100% capital subsidy and other default values; (3) 12% interest subsidy and other default values; (4) Price IDR 10 million per 100Wp PV, no loan and other default values.

Section 8 Adapting ARISE for Other Countries

1. Change the GIS files (i.e. *.dbf, *shp, *.shx), including social and technical data in DBF file. If your household data cannot be break down to urban-rural, dwelling owner – non dwelling owner, electricity access type then just use the variable of households with electricity access (*_UPLNO) and the variable of household without electricity access (*_RNEO).
2. Change the values of the Leontief Inverse Matrix in “m input output 6.txt”.
3. Change the values of annual urbanisation rate in procedure “LOAD”.
4. Change the values for variables “FIT2017” and “SUN_FIT”. If your country did not have feed-in tariff (FIT) policy, then the variables can be used as policy scenario.
5. Change the cost values to your country data.
6. Change the values of electricity tariff “TARIFF-450” and “TARIFF-6600” in procedure “DEFAULTVALUE” to your country tariff. In Indonesia, tariff 450 is a subsidised tariff for the poor household while tariff 6600 is the most expensive. 450 and 6600 indicate the limit of installed supply capacity (stated in volt-ampere/ VA) in the households.
7. Change the values of other parameters if necessary.
8. Any questions could be asked through email.

Contact & Citations

Any questions and error reporting could contact:

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