A Bike Ride from Cradle to Grave – Better Decision Making by using the Life-Cycle Costs Approach

The life-cycle costs (LCC*) approach is used to gain transparency, to compare variants and to have a reliable basis for long-term-budgeting of investments, maintenance and operation with the goal of most favourable total costs of ownership (TCO*) for a given level of service for reliability, availability, maintainability, safety, health and environment, functionality, comfort (RAMSHEFC).

* LCC and TCO are synonyms.

1. A methodology for better decisions

Good decisions have to take into account at least:

- Functionality;
- Consequences for both the short and long term;
- Costs and quality regarding LCC/TCO.

A decision can either be made for a single object (individual system) or for a greater amount of more or less identical objects (fleet or similar). The classification as (sub-)system is of minor interest, as long as its boundaries are clearly defined.

The longer the perspective, the more important is the life-cycle approach to avoid problems with funding or quality. Systems of public interest often have to be maintained and replaced repeatedly. The life span of these systems can sometimes be longer than the work life of the employees who deal with them. These systems can also be very costly. This is why they are usually financed by public funds and often run by governmental organisations: infrastructure and rolling stock in traffic systems, systems for supply and disposal of all kind etc.

Finding the right Life-Cycle Strategy

1) Reliable input data is crucial for costs, quantities of (sub-)systems (length, number, volume etc.) and quality figures. Data series have to cover a long period – or at least they have to be validated, for instance by checking the resulting life span, if the replacement rate is only known over a short period. In short: Only what gets measured can be managed!

2) One has to know and define the levels of service.

3) The calculation of LCC has to be done in variants. ”Variant zero” is both meaningful as a basis to compare the impact of a decision with the present (quality, budget etc.) and as the ”no changes” option.

4) To define an intelligent maintenance and replacement strategy, it is crucial to understand the technical aspects over the life span of the system and beyond.

These steps can be passed through iteratively.

2. Calculation of Life-Cycle Cost per year

It is recommended to proceed from rough to detail:

1 Define the problem.

2 Make a first, brief calculation of the LCC
(as preparation for the next step).

3 Get a better insight by interviewing experts, benchmarking, measuring and gathering data.

The life-cycle approach is an opportunity to get to know a system by interviewing experts, gathering information about its past and present behaviour and by benchmarking with competitors.

Note that benchmarking in this context is voluntarily conducted by competitors with equal interests. One should never be afraid of comparing apples with oranges, because it can be helpful to impartially explore discrepancies and varieties to achieve in-depth understanding.

4 Revise the calculation:
Comparison of variants, budget forecast etc.

5 Review by using the two approaches described hereafter: top-down and bottom-up.

To reduce complexity, certain estimations and simplifications are inevitable. Without the courage for clever assumption, it can become cumbersome.

Approach: Bottom-up

The costs per year of an average, individual system of a kind is multiplied by the number of identical systems (m) represented by the average system - resulting in the yearly costs of the whole fleet.

$$LCC_{fleet}/a = m \cdot \left(\frac{I_{system}}{n_I} + e_{system,a}\right) \qquad [\$, € \text{ etc.}]$$

$$e_{system,a} = \frac{e_{system}}{n_e} \qquad \text{for intervention period} \neq 1 \text{ year}$$

m = number of identical, individual systems, represented by average figures a = annum (lat.) = year

I = Investment for replacement [$, € etc.]

n_I = Life span between replacement [years]

e = Running costs e_a = yearly expenses [$, € etc.]

n_e = Intervention period for running costs [years]

Note that for the comparison of two (or more) variants with different life spans, this method gives the most robust results. Alternatively, one could calculate the LCC of both variants over the duration of the shorter life span n_{short} but would then have to assume the residual value of the system with the longer life span at the end of n_{short}. One more parameter means one more uncertainty about the accuracy of the data base – which can be avoided by using the equation presented (see also the first page of the appendix).

Approach: Top-down

In reverse to the bottom-up-approach, one can deduce the average costs of an individual system "top-down" by dividing the (known) yearly costs of the fleet by the number of individual systems.

$$LCC_{system}/a = \frac{1}{m}\left(I_{fleet,a} + e_{fleet,a}\right) \quad [\$, € \text{ etc.}]$$

Rates for Replacement and Intervention

Unless what approach, the rates are $\frac{1}{n_I}$ and $\frac{1}{n_e}$.

3. A Bike Ride from Cradle to Grave (examples)

One may consider a bicycle as a lifelike and realistic prototype for any calculation of LCC. The definition of an individual system is: one ordinary bicycle (no clothing, trailer or extras). Note that this definition includes a whole bunch of assumptions about the characteristics, that have to be specified in the process of calculation, comparison and decision. For instance, the chosen level of comfort and functionality (gear shift, shock absorbers etc.) can be decisive for both replacement and running costs.

Type of System		Courier service	Everyday use bike	
Life span of ind. system	n_I	**10**	**15**	**[a]**
Replacement rate of ind. system		0.1	0.07	[1/a]
Replacement costs / ind. sys.		**3.0**	**1.5**	**[k€]**
Running costs / ind. sys.		0.3	0.1	[k€/a]
Intervention cost	e_{system}	0.3	0.3	[k€]
Intervention period	n_e	1	3	[a]
LCC = TCO		6	3	[k€]
LCC/a = TCO/a		**0.6**	**0.2**	**[k€/a]**
Yearly mileage*		15'000	1'000	[km]
Specific costs [€Cent/km*a]		4	20	

* 60 km / d * 250 d / a = 15'000 km/a

4 km / d * 150 d / a + 400 km/a = 1'000 km/a

Fig. 1 Comparison of two types of an individual system with different use cases (bicycles).

All calculations in these examples are conducted with average numbers. The figures were estimated and discussed with the management of "Veloblitz Zurich".

Courier Service A vs. Courier Service B

Fig. 2 shows two almost identical systems. The only difference is, that the system of type B has a shorter life span und lower replacement costs (red: discrepancies). This reveals the effects on the other parameters.

Type of System		A	B	
System-LCC/a		**30**	**35**	**[k€/a]**
↓↑ Budget for replacements		15	20	[k€/a]
↓↑ Budget for running costs		15	15	[k€/a]
Size of fleet		**50**	**50**	**[no.]**
Duration of installation	t_n	**15**	**15**	**[a]**
Replacement rate		5	10	[sys/a]
↓ Top-down Approach ↑ bottom-up				
Replacement rate of ind. sys.		0.1	0.2	[1/a]
Life span of ind. system°	n_I	**10**	**5**	**[a]**
Introduction of system"	t_0	2.5	2.5	[a]
Variation* of n_I	$v_n = n_I / 2$	5	2.5	[a]
Life span of system $N = t_0 + t_n + n_I + v_n$		**32.5**	**25**	**[a]**
↓ Top-down Approach ↑ bottom-up				
Replacement costs / ind. sys.		**3**	**2**	**[k€]**
↓↑ frame		1	0.8	[k€]
↓↑ Set of components		2	1.2	[k€]
Running costs / ind. sys.		**0.3**	**0.3**	**[k€/a]**
↓↑ Drive/transmission		0.2	0.2	[k€/a]
↓↑ Set of tyres		0.05	0.05	[k€/a]
↓↑ Set of brakes		0.02	0.02	[k€/a]
↓↑ Lightning system		0.01	0.01	[k€/a]
↓↑ Saddle and handlebar		0.01	0.01	[k€/a]
↓↑ Rest of subsystems		0.01	0.01	[k€/a]

° average life span n_I (theoretical value)

" prototyping, testing etc.

* statistical variation v_n of life span n_I ($v_n = \pm 50\ \%$) leads to longer life span of system s.

Fig. 2 Comparison of two similar types of a system A and B with two approaches bottom-up and top-down (indicating the starting point of the calculation).
> see also the first page of the appendix.

Note that for short system cycles ($t_n < n_I$), there will be several systems in parallel use. The effort necessary to handle regulations and instruction manuals, spare parts, training etc. thus increases.

4. Optimising Life-Cylce Costs

Business Model

Veloblitz Zurich has 80 active drivers, of which about 15 are in service at a given time. Its selling proposition is: fast, reliable and on time for a moderate price. The company's strategy is: Happy employees, who enjoy flexible working days and hours; an optimised cost structure and cooperation with other couriers for longer distances (SBB amongst others).

According to the management, driving style and everyday bike care matter. Rowdy drivers (curbstones!) or perfectionists (lubrication, cleaning!) can easily double or halve the costs for their bikes. Therefore the following applies:

- Bikes are owned by the driver, who will usually take good care of it because he or she bears the risk.
- Veloblitz runs a garage with a mechanic who is employed half-time. The garage is located right were the drivers wait for orders and offers support for buying and equipping bikes (2/3 of the time) as well as for maintenance and troubleshooting (1/3 of the time). The mechanic is the main knowledge carrier. He focusses this knowledge in a standard bike with "silver standard" (see below). Drivers only pay the net costs for his working hours and they profit from volume discounts.
- Bags are owned by the company. They carry the logo. Shirts have to be bought and worn.

Some facts about solutions, that may astonish:

- Shoe brakes are used instead of disk brakes, because they are light and cheap and only a little less comfortable (more force is used).
- No compressor to inflate tyres is offered, but a simple, easy-to-use floor pump, that can be used during waiting times: Very cheap to buy and use and reliable as well.
- As progress in bike-technology is not very fast, one does not make a big mistake by relying on established, known components.
- An appropriate choice for a courier bike would be a robust race-frame, which is durable and light. The components should also be reliable and durable and easy to repair and maintain.

  This is described as the "silver standard" (B-component) by Veloblitz. A "gold standard" would be a Kevlar-frame: even lighter, but much too expensive for the purpose of a courier-service .

  Typical A-components are: wheels, bearings and saddle. B-components are: brakes, drive and transmission, C-components are tyres, brake pads and lights.

Hereafter, all examples are chosen to lower the LCC/a of the fleet by 1/6, that is from 30 to 25 k€/a.

Mathematical Determination of Optimisation

In a steady state, all parameters are constant over time – including quality. To reduce the LCC/a, there are two ways of optimisation: improve the individual systems or reduce the fleet: there is no cheaper system than the one that has *never* been installed!

- Lower the number of individual systems m;
- Lower the replacement cost I ;
- Extend the life span n_{I}

  and thus lower the replacement rate $\frac{1}{n_I}$;
- Lower the running costs yearly expenses by either lowering the cost for each intervention or by extending the intervention period for maintenance, operation and troubleshooting.

  Note that this can be done with or without replacing the existing, individual systems.
- Reduce requirements (RAmSHEFC).

  A standard has to be defined to meet the needs of operation in terms of reliability, availability, safety, health and environment as well as functionality and comfort.

  On the other hand, an optimal intervention strategy has to be defined (rate and type of intervention), considering maintainability and troubleshooting. Those are strongly related to life span and replacement costs.

Each change is calculated separately according to the principle of ceteris paribus (i.e. all other things being equal). If more than one parameter is changed, the results of each calculation have to be superposed. It seems obvious that real optimisation has to take into account every impact on the parameters for costs, quality and functionality. See the appendix for illustrations of these calculations.

Lowering the number of bicycles	**A**	**B**	
System-LCC/a	**30**	**25**	**[k€/a]**
Budget for replacements	15	12.5	[k€/a]
Budget for running costs	15	12.5	[k€/a]
Size of fleet	**50**	**42**	**[no.]**
Replacement rate	5	4.2	[sys./a]
Transition of system* N = $n_{\mathrm{I}} + v_n$	**15 ***		**[a]**
↓ Top-down Approach ↑ bottom-up			
Replacement rate of ind. sys.	0.1	0.1	[1/a]
Life span of individ. system n_{I}	**10**	**10**	**[a]**
Replacement costs / ind. sys.	**3**	**3**	**[k€]**
Running costs / ind. system	**0.3**	**0.3**	**[k€/a]**

Fig. 3 Optimising LCC by lowering the number of individual systems.

* Note that in this example, every year 1/6 of the individual systems pending for renewal are removed. One could also decide to remove 16.7 % of the systems at once in order to reduce the duration of transition to zero. This could be favourable, provided removal costs are equal in both variants.

Lowering the replacement costs	A	B	
System-LCC/a	**30**	**25**	**[k€/a]**
Budget for replacements	15	10	[k€/a]
Budget for running costs	15	15	[k€/a]
Size of fleet	**50**	**50**	**[no.]**
Replacement rate	5	5	[sys./a]
Transition of system* N = $n_I + v_n$	**0 ***		**[a]**
↓ Top-down Approach ↑ bottom-up			
Replacement rate of ind. sys.	0.1	0.1	[1/a]
Life span of individ. system n_I	**10**	**10**	**[a]**
Replacement costs / ind. sys.	**3**	**2**	**[k€]**
Running costs / ind. system	**0.3**	**0.3**	**[k€/a]**

Fig. 4 Optimising LCC by lowering the replacement costs.

* Note that all measures must have an immediate impact on costs and that they are independent of the installed systems: scale effects for replacement work, process optimisation, lower requirements for functionality, operation pauses etc.

Extending the life-span	A	B	
System-LCC/a	**30**	**25**	**[k€/a]**
Budget for replacements	15	10	[k€/a]
Budget for running costs	15	15	[k€/a]
Size of fleet	**50**	**50**	**[no.]**
Replacement rate	5	3.3	[sys./a]
Transition of system* N = $n_I + v_n$	**15 ***		**[a]**
↓ Top-down Approach ↑ bottom-up			
Replacement rate of ind. sys.	0.1	0.07	[1/a]
Life span of individ. system n_I	**10**	**15**	**[a]**
Replacement costs / ind. sys.	**3**	**3**	**[k€]**
Running costs / ind. system	**0.3**	**0.3**	**[k€/a]**

Fig. 5 Optimising LCC by extending the life span.

* Note that the duration of transition is a matter of definition. Due to statistical variation, it will take quite a long time until the budget for replacement and the replacement rate will have reached the new level of average values for variant B.

Lowering the running costs by optimising maint., operation or troubleshooting	A	B	
System-LCC/a	**30**	**25**	**[k€/a]**
Budget for replacements	15	15	[k€/a]
Budget for running costs	15	10	[k€/a]
Size of fleet	**50**	**50**	**[no.]**
Replacement rate	5	5	[sys./a]
Transition of system* N = $n_I + v_n$	**0 ***		**[a]**
↓ Top-down Approach ↑ bottom-up			
Replacement rate of ind. sys.	0.1	0.1	[1/a]
Life span of individ. system n_I	**10**	**10**	**[a]**
Replacement costs / ind. sys.	**3**	**3**	**[k€]**
Running costs / ind. system	**0.3**	**0.2**	**[k€/a]**

Fig. 6 Optimising LCC by optimising running costs by optimising maintenance, operation or troublesh.

* Note that all measures must have an immediate impact on costs and that they are independent of the installed systems: scale effects for replacement work, process optimisation, lower requirements for functionality, operation pauses etc.

Lowering running costs by installing optimised systems – all of a sudden	A	B	
System-LCC/a	**30**	**25**	**[k€/a]**
Budget for replacements *	15	15	[k€/a]
Budget for running costs	15	10	[k€/a]
Size of fleet	**50**	**50**	**[no.]**
Replacement rate	5	5	[sys./a]
Transition of system* N = $n_I + v_n$	**0**		**[a]**
↓ Top-down Approach ↑ bottom-up			
Replacement rate of ind. sys.	0.1	0.1	[1/a]
Life span of individ. system n_I	**10**	**10**	**[a]**
Replacement costs / ind. sys.	**3**	**3**	**[k€]**
Running costs / ind. system	**0.3**	**0.2**	**[k€/a]**

Fig. 7 Optimising LCC by optimising running costs by installing optimised systems – all of a sudden.

* Note that all systems have to be replaced at once, which requires an extra budget for replacement. It has to be as high as the budget for n_I years (10 a). On an average calculation base, a budget of $n_I/2$ years must be considered an extra-investment. In this example, this is 75 k€. Thus, this investment will amortise after 15 years: - 5k€/a * 15 a = - 75 k€ for the running costs (without taking into account discounting of future cash flows to the present value).

Lowering running costs by installing optimised systems – ordinary repl. cycles	A	B	
System-LCC/a	**30**	**25**	**[k€/a]**
budget for replacements *	15	15	[k€/a]
budget for running costs	15	10	[k€/a]
Size of fleet	**50**	**50**	**[no.]**
Replacement rate	5	5	[sys./a]
Transition of system* N = $n_I + v_n$	**15**		**[a]**
⬇ Top-down Approach ⬆ bottom-up			
Replacement rate of ind. sys.	0.1	0.1	[1/a]
Life span of individual systemn_I	**10**	**10**	**[a]**
Replacement costs / ind. sys.	**3**	**3**	**[k€]**
Running costs / ind. system	**0.3**	**0.2**	**[k€/a]**

Fig. 8 Optimising LCC by optimising running costs by installing optimised systems – ordinary replacement cycles.

5. Conclusion and further discussion

To successfully manage systems and systems of systems (fleets), a clear vision of the LCC / TCO is needed – including the possible optimisations. An optimal intervention strategy has to take into account the relations and dependencies between

- Operation, maintainability and troubleshooting;
- Life span;
- Replacement costs.

Thus, an in-depth understanding of the technical systems and a reliable database over a longer period is needed.

Note that the opposite effects can also be true: deterioration, i.e. either higher costs for replacements or higher running cost for the system / fleet. A great variety of types of systems with the same basic functionality due to (too) short innovation cycles can also be unfavourable.

Further discussions can be held about discounting the yearly cash flows to the present value, i.e. comparing net present values with the goal of taking into account the value of cash over time.

Costs can considered related to phases in the life-cycle, to the technical structure (subsystems) and to the cost classification (investment or running, human power, equipment or supplies etc.)

Further discussions could also focus on the value of time (in case of system down time) and its monetarisation, the costs of risks etc. etc.

6. Appendixes: Illustrations

Comparison of two similar types of a system A and B with two approaches bottom-up and top-down (indicating the starting point of the calculation) (fig. 2)

This appendix includes the information from fig. 1.

Optimising LCC by lowering the number of individual systems. (fig. 3)

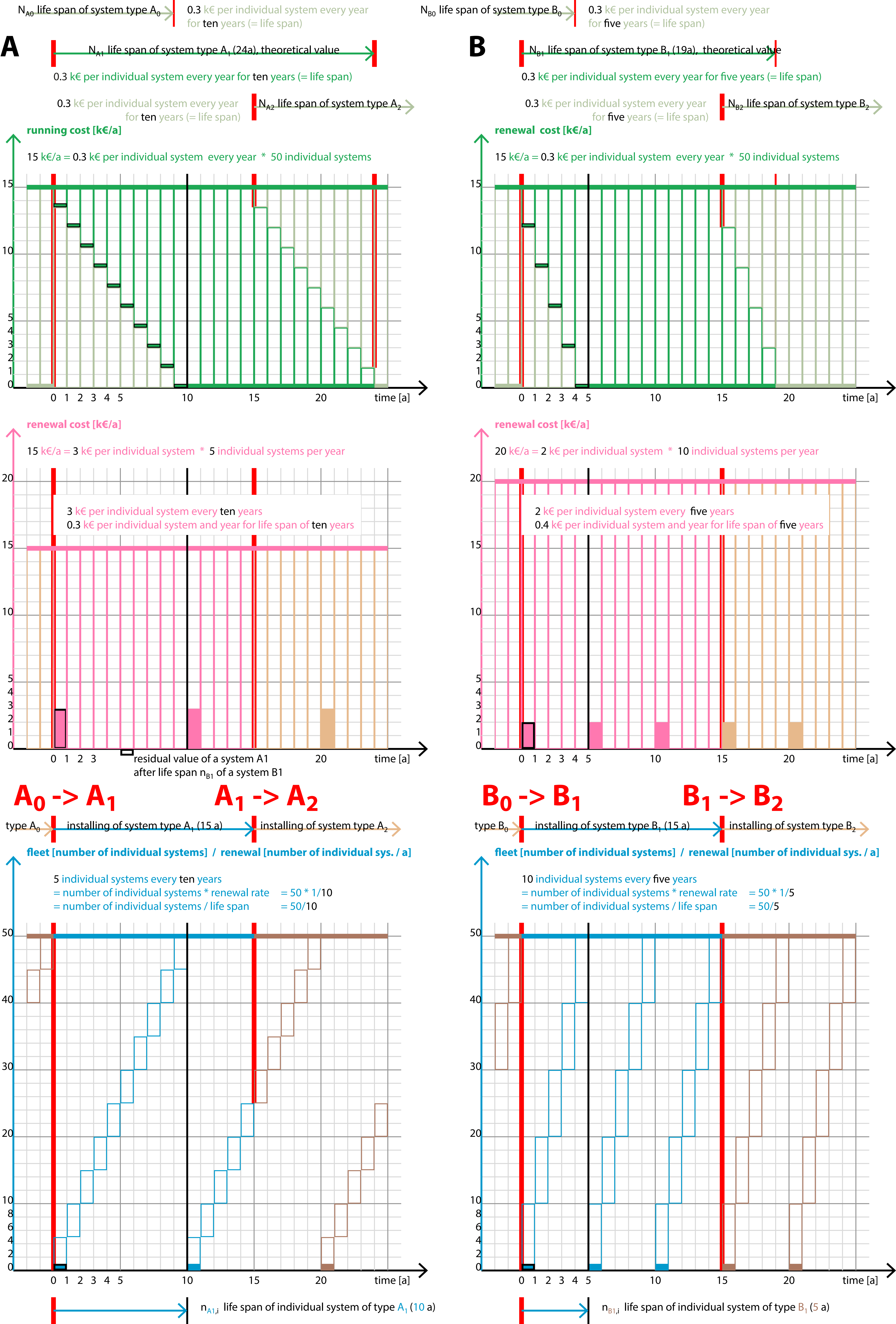
Optimising LCC by lowering the replacement costs. (ig. 4)

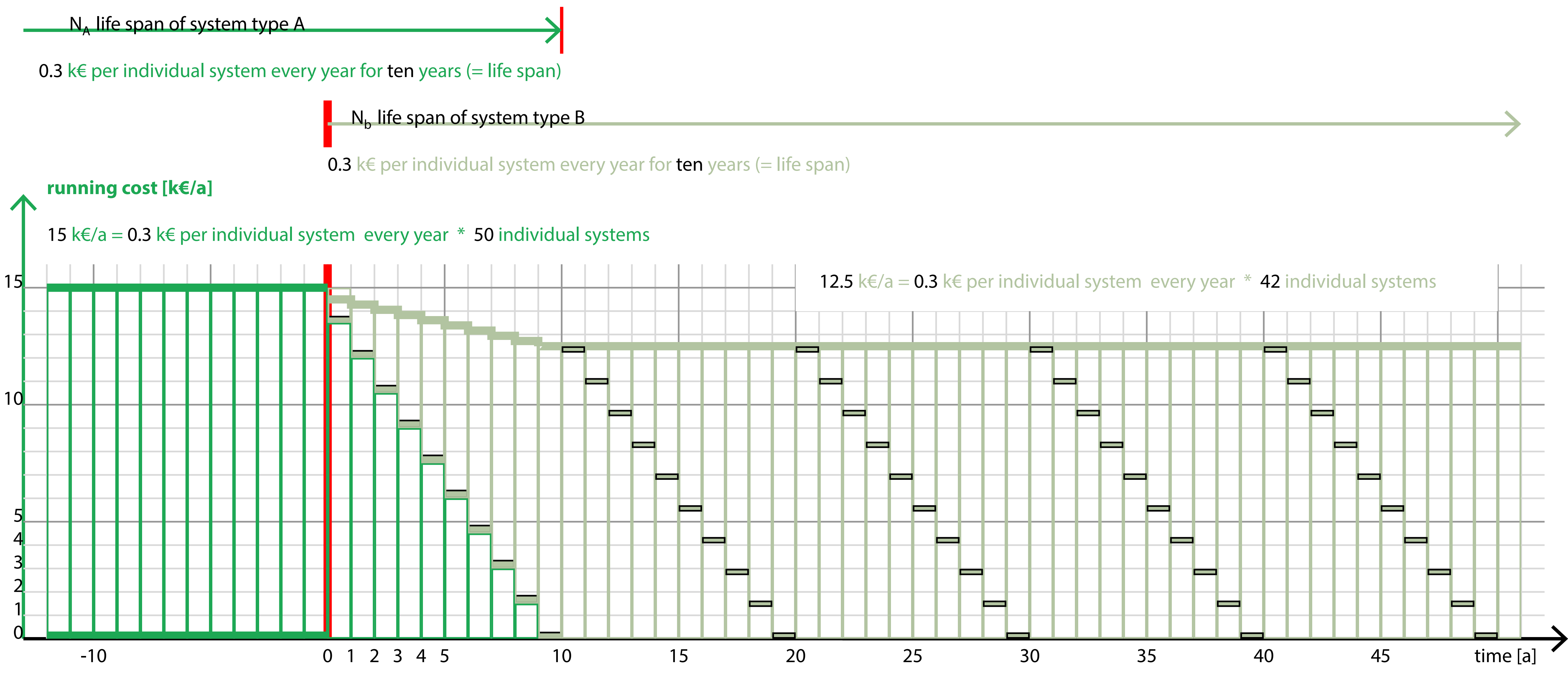
Optimising LCC by extending the life span. (fig. 5)

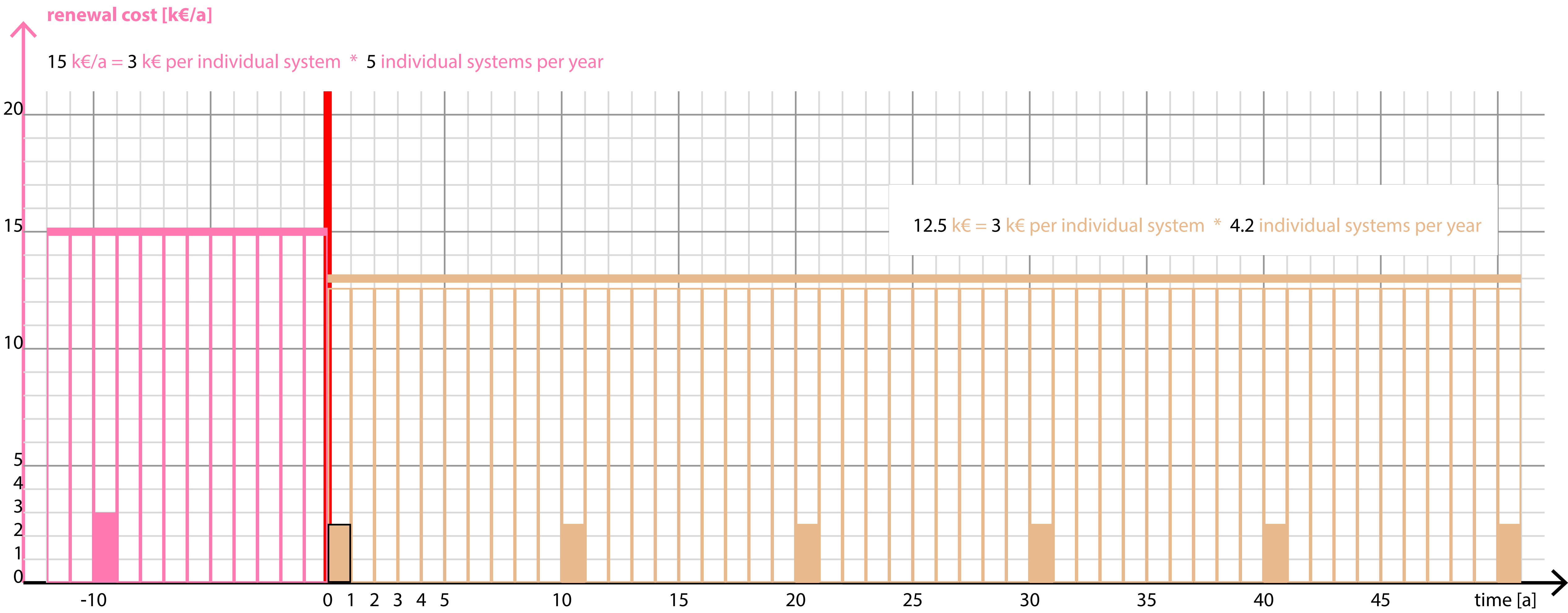
Optimising LCC by optimising running costs by optimising mantenance, operation or troubleshooting. (fig. 6)

Optimising LCC by optimising running costs by installing optimised systems – all of a sudden. (fig. 7)

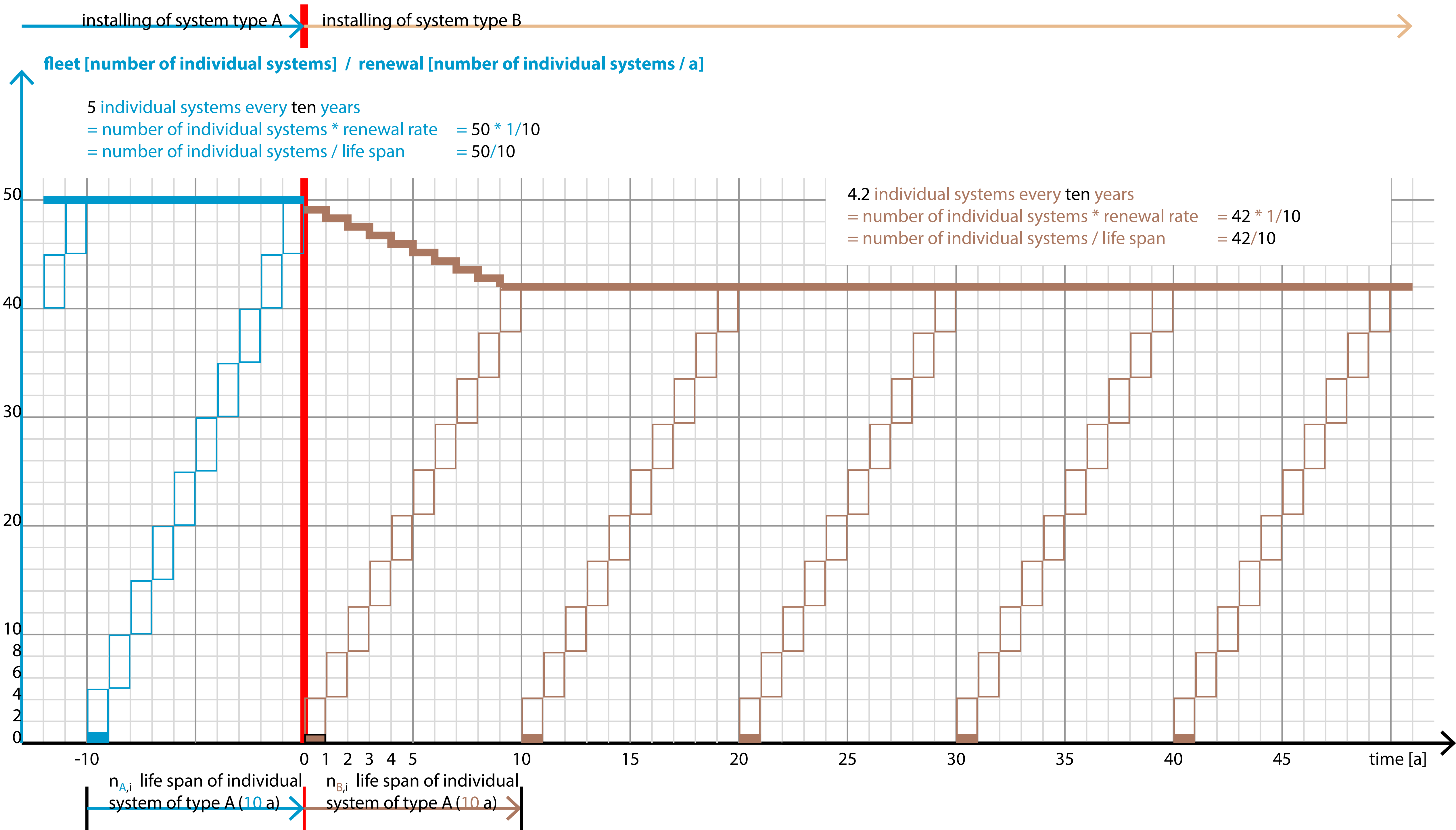
Optimising LCC by optimising running costs by installing optimised systems – ordinary replacement cycles. (fig. 8)

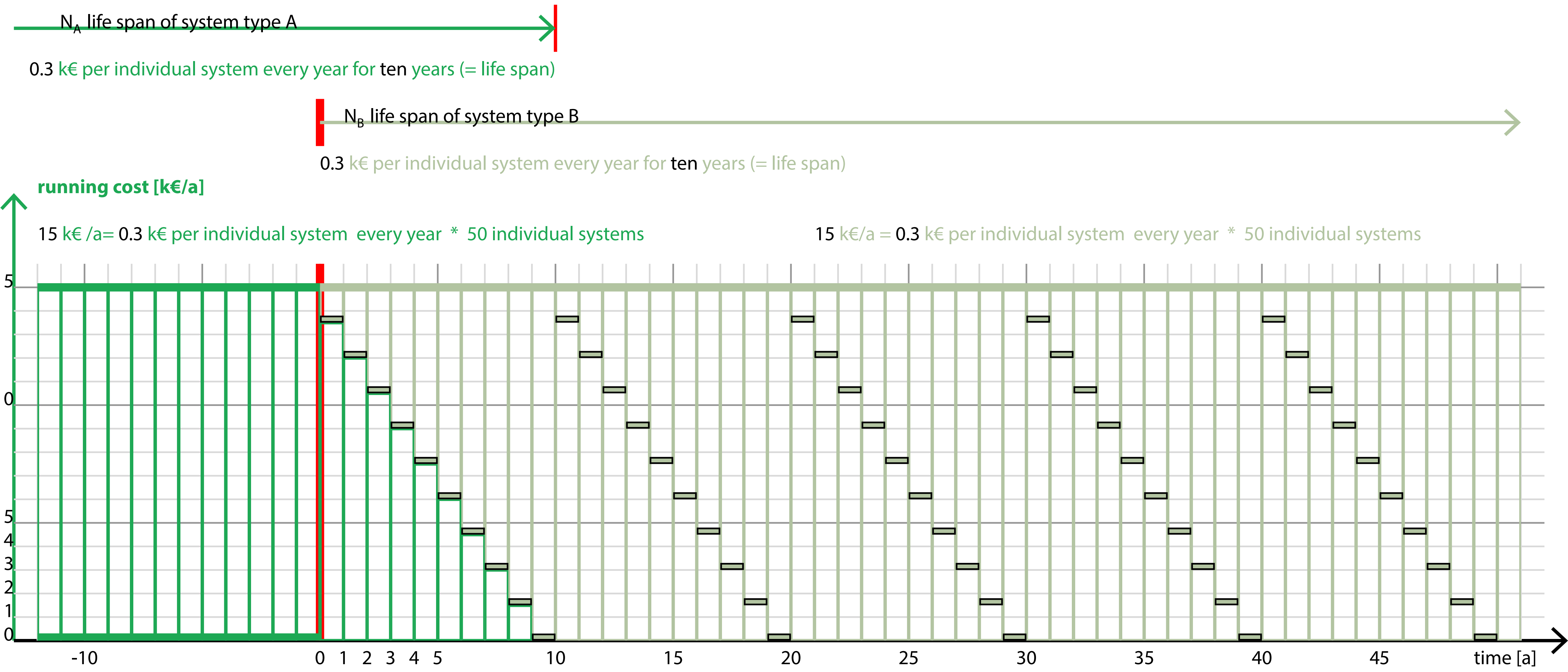

A
N_A0 life span of system type A_0
0.3 k€ per individual system every year for ten years (= life span)
N_A1 life span of system type A_1 (24a), theoretical value
0.3 k€ per individual system every year for ten years (= life span)
0.3 k€ per individual system every year for ten years (= life span)
N_A2 life span of system type A_2
running cost [k€/a]
15 k€/a = 0.3 k€ per individual system every year * 50 individual systems
15
10
5
4
3
2
1
0
0 1 2 3 4 5 10 15 20 time [a]
renewal cost [k€/a]
15 k€/a = 3 k€ per individual system * 5 individual systems per year
20
3 k€ per individual system every ten years
0.3 k€ per individual system and year for life span of ten years
15
10
5
4
3
2
1
0
0 1 2 3 20 time [a]
residual value of a system A1
after life span n_B1 of a system B1
A0 -> A1
A1 -> A2
type A_0
installing of system type A_1 (15 a)
installing of system type A_2
fleet [number of individual systems] / renewal [number of individual sys. / a]
5 individual systems every ten years
= number of individual systems * renewal rate = 50 * 1/10
= number of individual systems / life span = 50/10
50
40
30
20
10
8
6
4
2
0
0 1 2 3 4 5 10 15 20 time [a]
n_A1,i life span of individual system of type A_1 (10 a)
B
N_B0 life span of system type B_0
0.3 k€ per individual system every year for five years (= life span)
N_B1 life span of system type B_1 (19a), theoretical value
0.3 k€ per individual system every year for five years (= life span)
0.3 k€ per individual system every year for five years (= life span)
N_B2 life span of system type B_2
renewal cost [k€/a]
15 k€/a = 0.3 k€ per individual system every year * 50 individual systems
15
10
5
4
3
2
1
0
0 1 2 3 4 5 10 15 20 time [a]
renewal cost [k€/a]
20 k€/a = 2 k€ per individual system * 10 individual systems per year
20
2 k€ per individual system every five years
0.4 k€ per individual system and year for life span of five years
15
10
5
4
3
2
1
0
0 1 2 3 4 5 10 15 20 time [a]
B0 -> B1
B1 -> B2
type B_0
installing of system type B_1 (15 a)
installing of system type B_2
fleet [number of individual systems] / renewal [number of individual sys. / a]
10 individual systems every five years
= number of individual systems * renewal rate = 50 * 1/5
= number of individual systems / life span = 50/5
50
40
30
20
10
8
6
4
2
0
0 1 2 3 4 5 10 15 20 time [a]
n_B1,i life span of individual system of type B_1 (5 a)

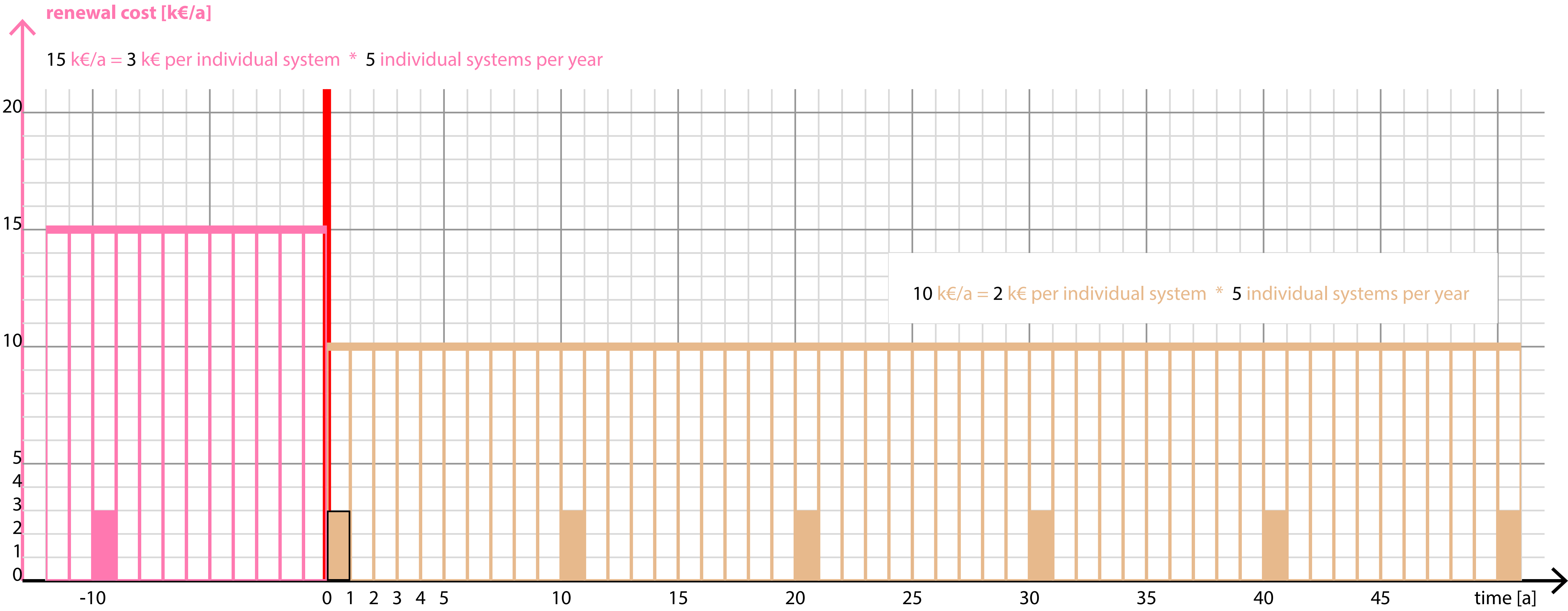




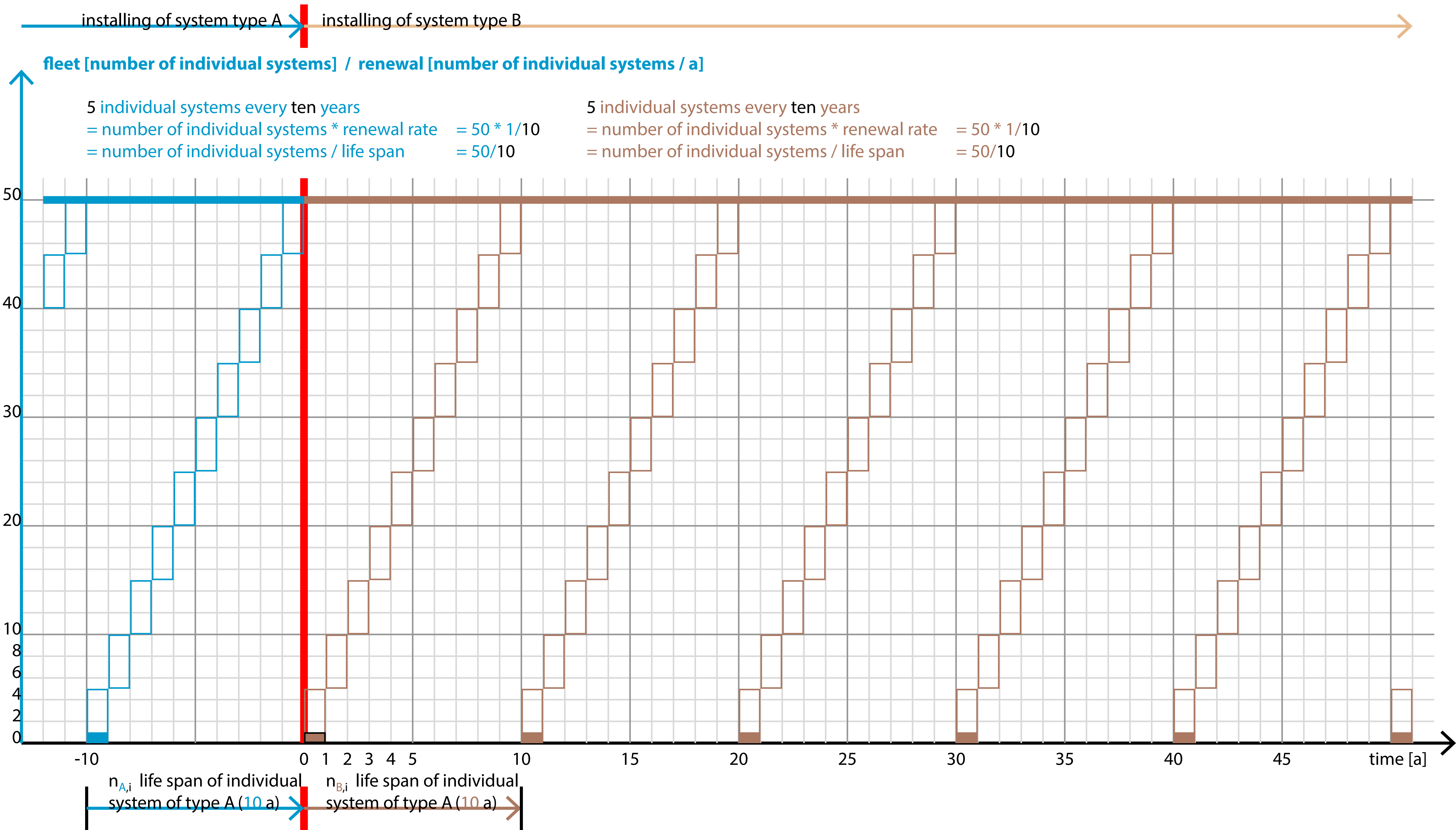
A -> A with a lower number of individual systems (83 %)

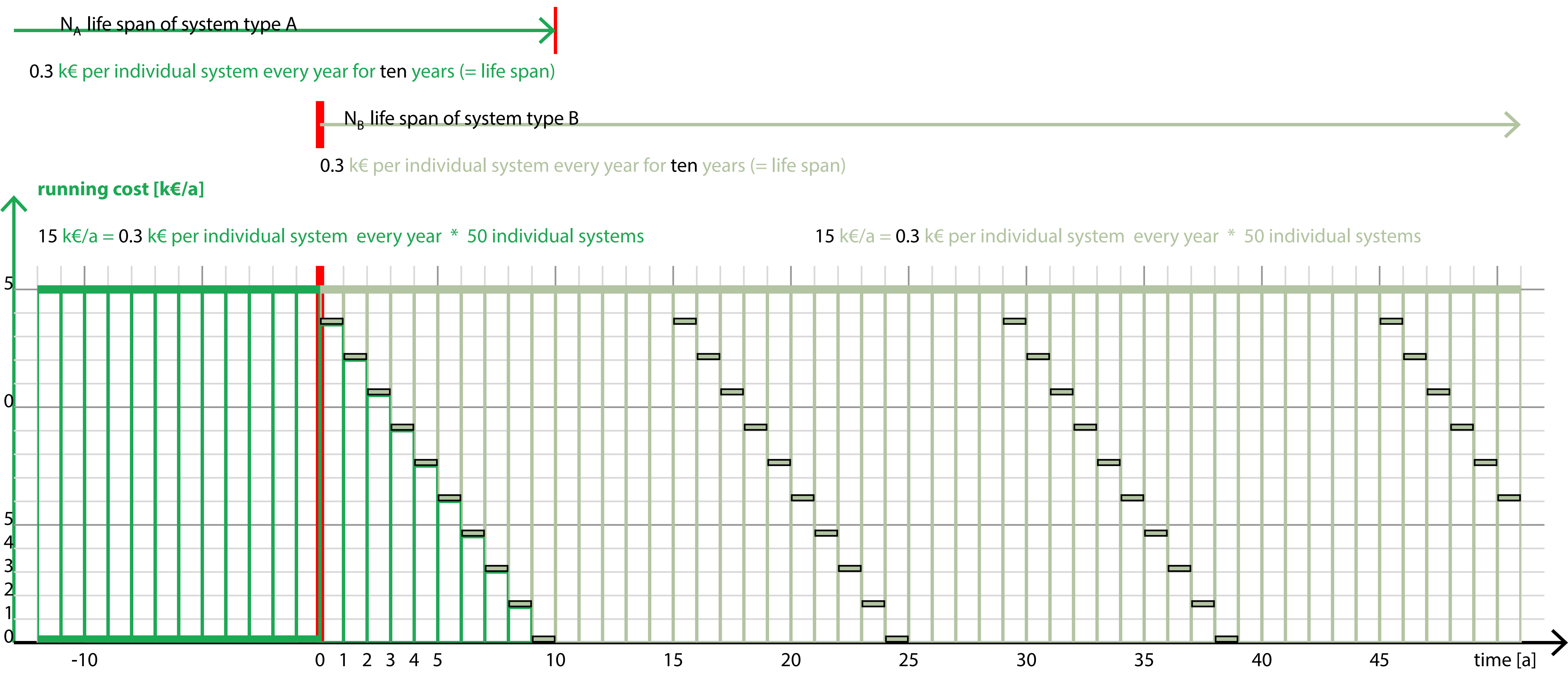






A -> B with lower replacement costs (- 33 %)




N_A life span of system type A

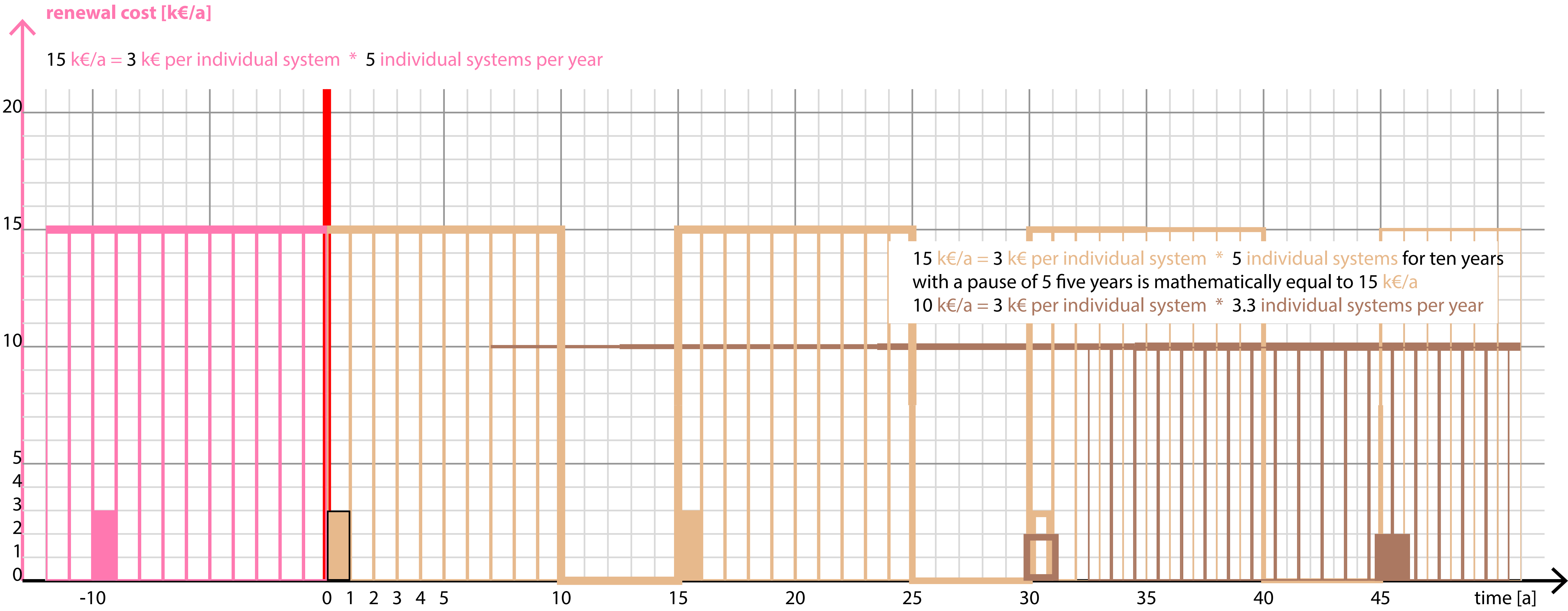
0.3 k€ per individual system every year for ten years (= life span)

N_B life span of system type B

0.3 k€ per individual system every year for ten years (= life span)

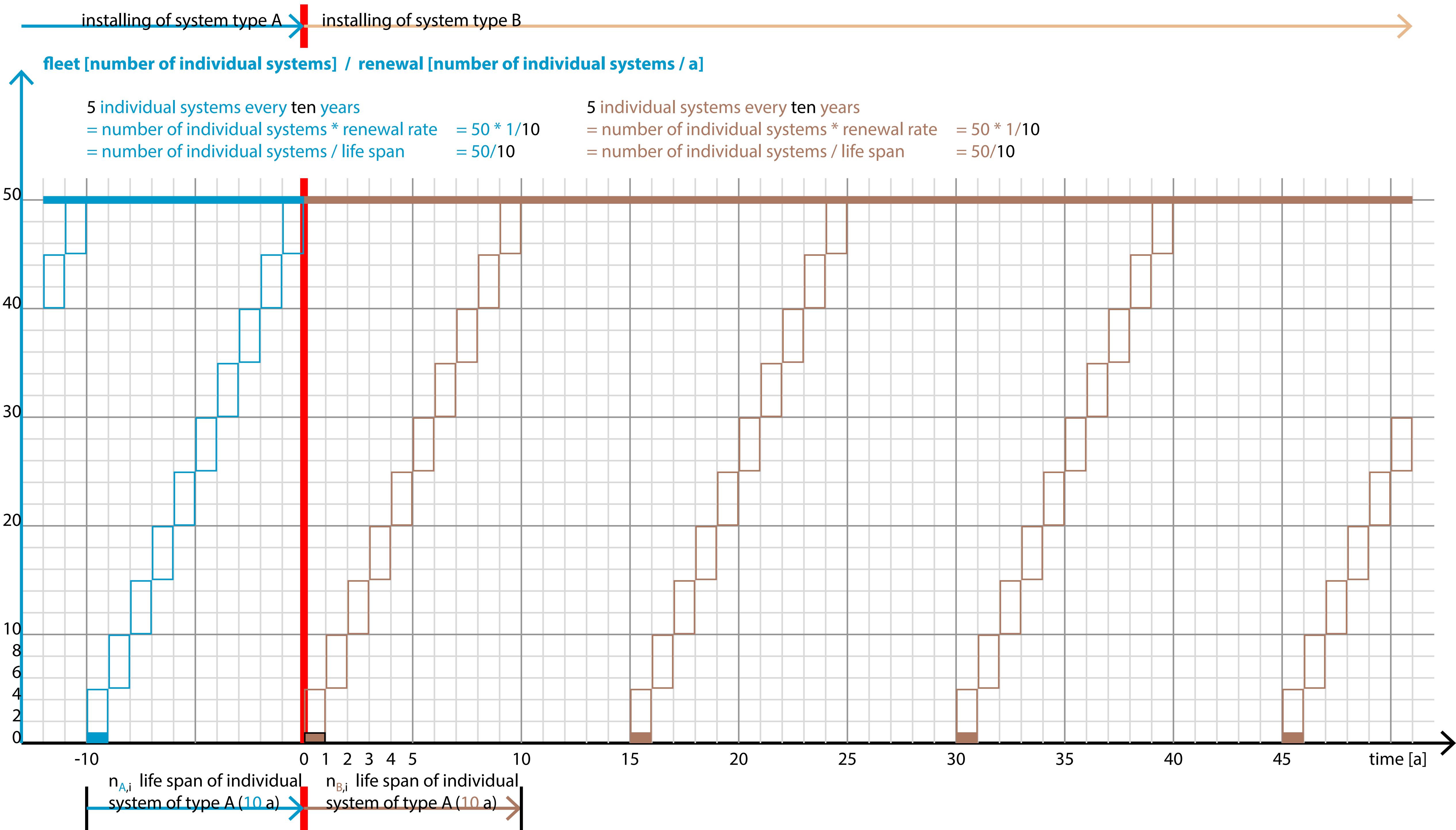
15 k€/a = 0.3 k€ per individual system every year * 50 individual systems

15 k€/a = 0.3 k€ per individual system every year * 50 individual systems


15 k€/a = 3 k€ per individual system * 5 individual systems per year

15 k€/a = 3 k€ per individual system * 5 individual systems for ten years
with a pause of 5 five years is mathematically equal to 15 k€/a
10 k€/a = 3 k€ per individual system * 3.3 individual systems per year

A -> B with extended life span (+ 50 %)


installing of system type A

installing of system type B

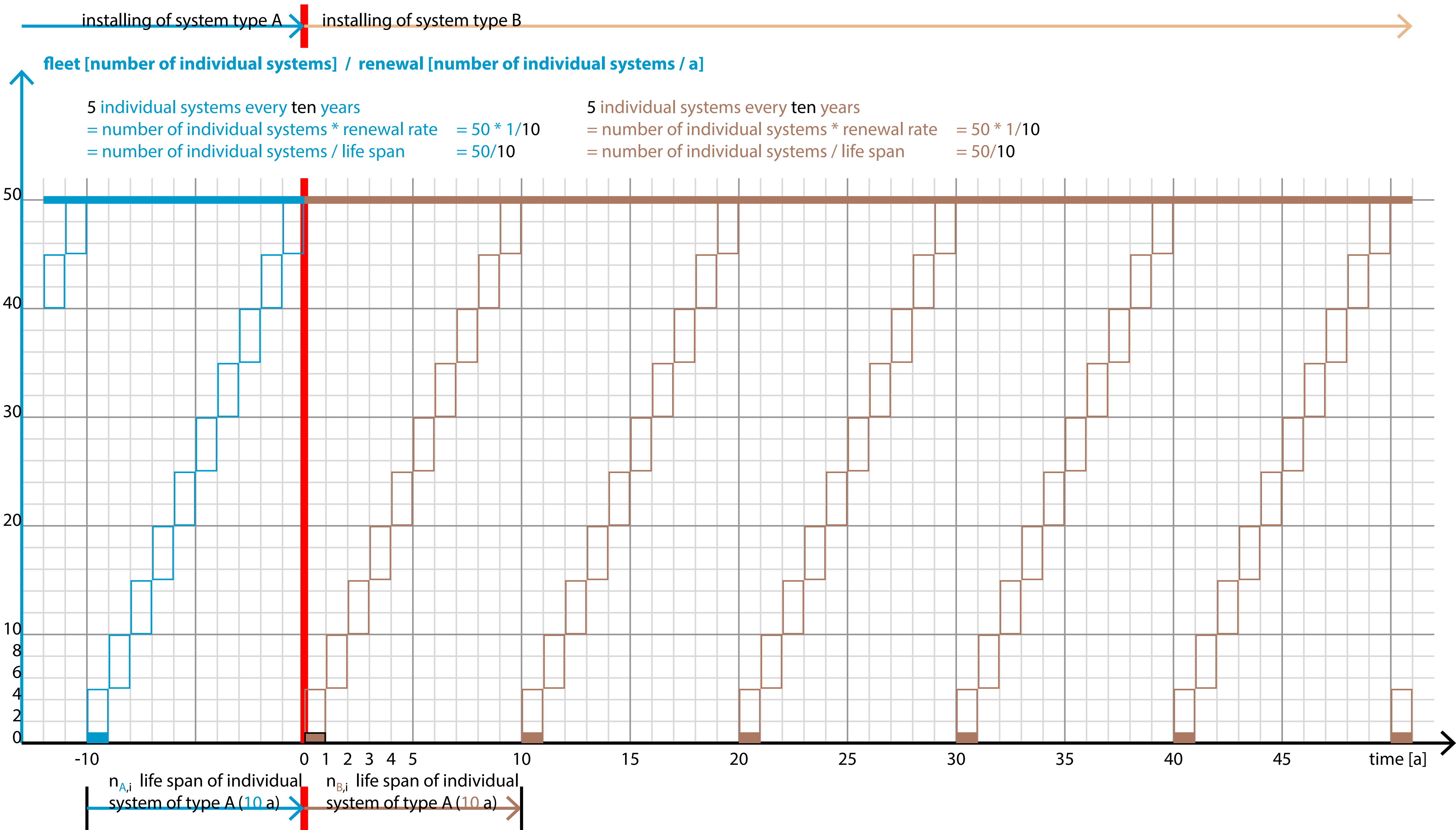
5 individual systems every ten years
= number of individual systems * renewal rate = 50 * 1/10
= number of individual systems / life span = 50/10

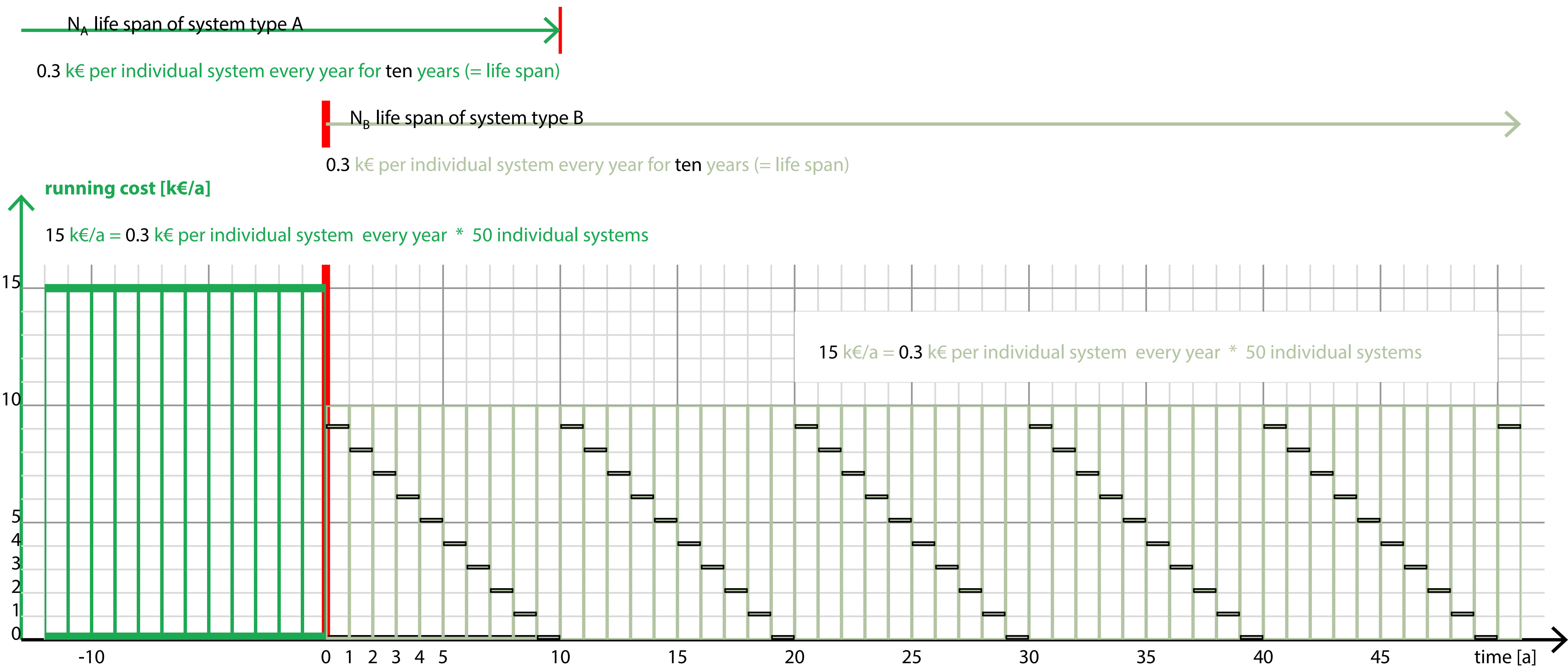
5 individual systems every ten years
= number of individual systems * renewal rate = 50 * 1/10
= number of individual systems / life span = 50/10

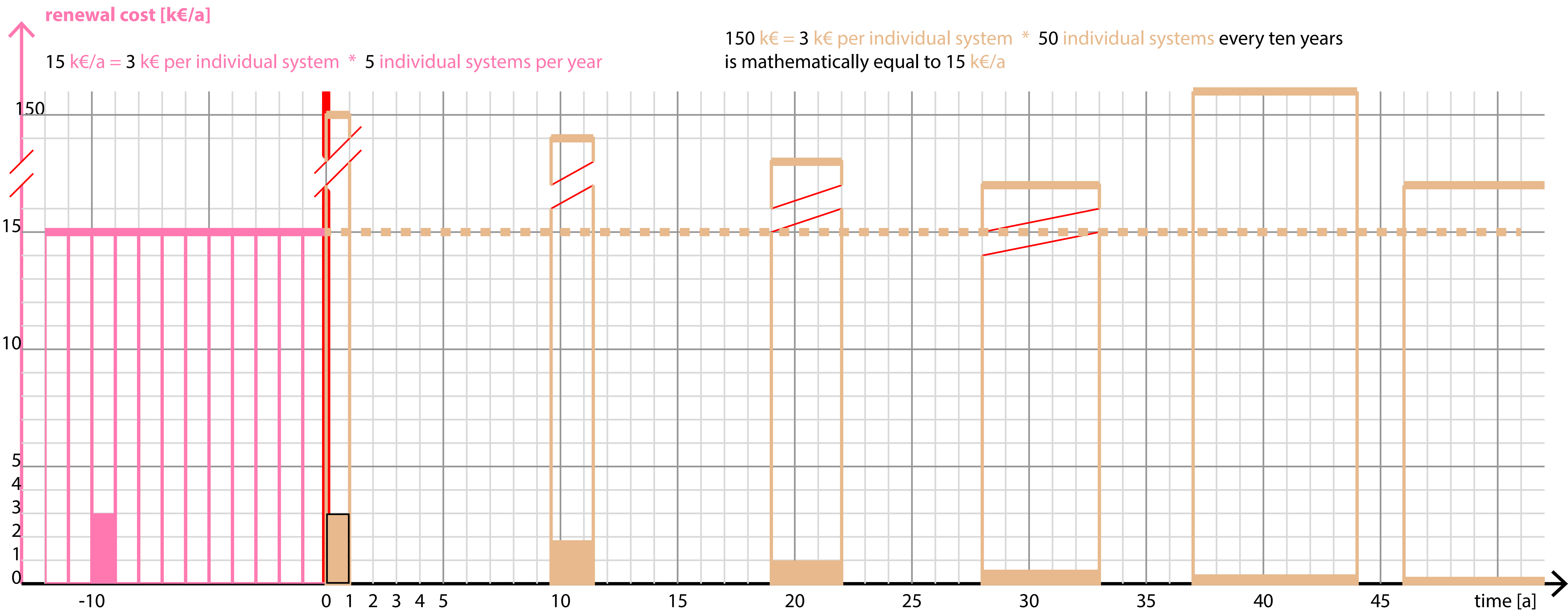
$n_{A,i}$ life span of individual system of type A (10 a)

$n_{B,i}$ life span of individual system of type A (10 a)

A -> B with optimised running costs (- 33 %)

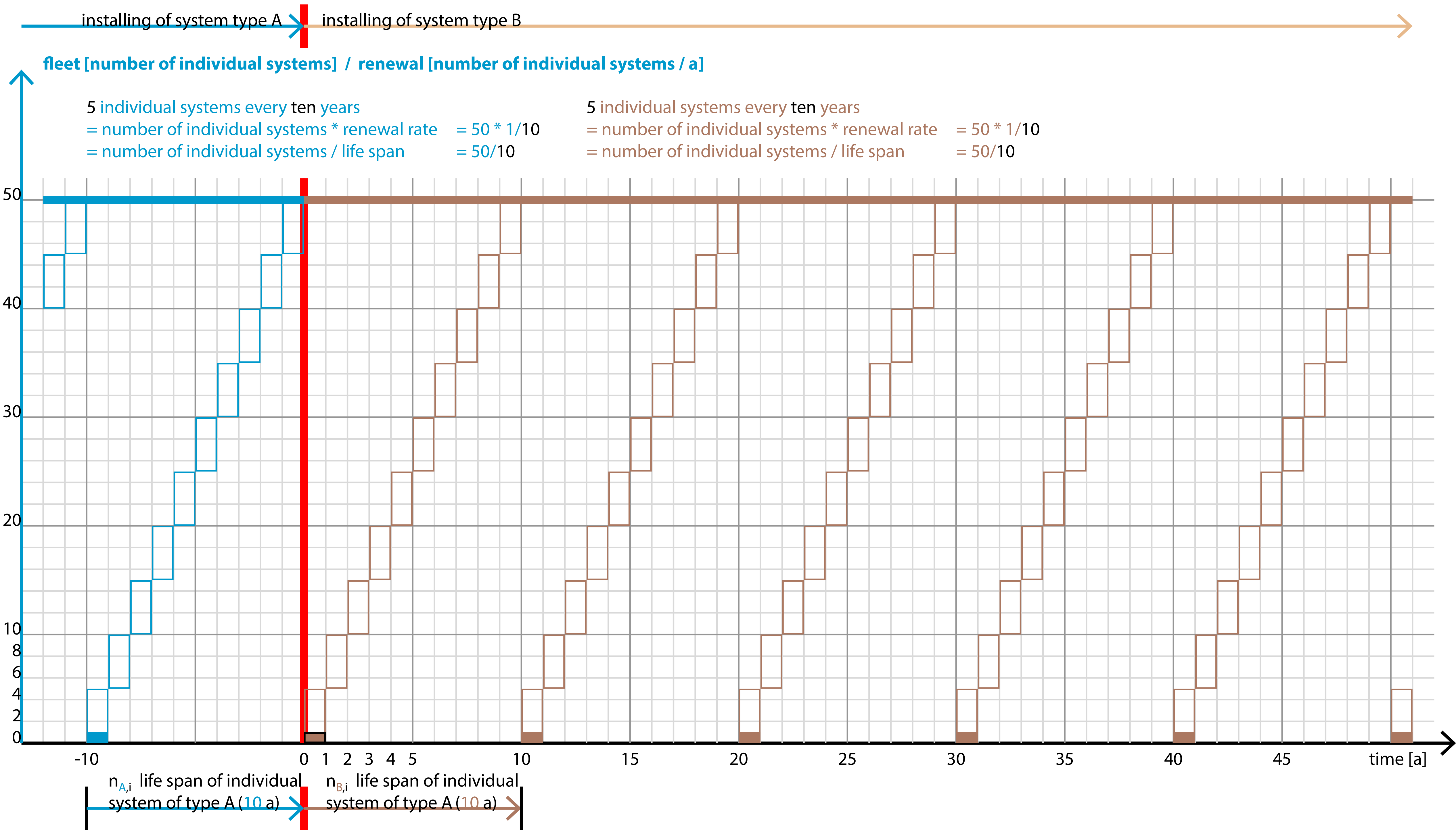


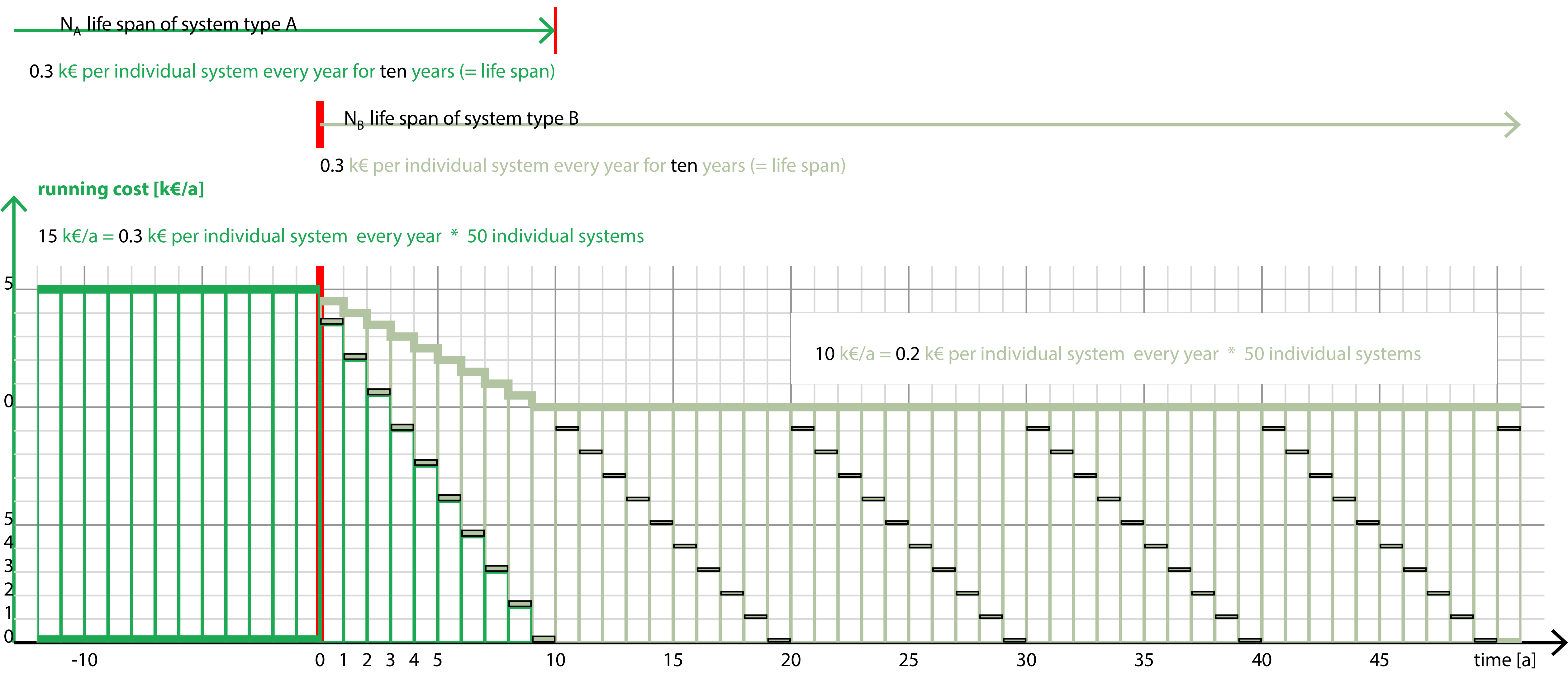


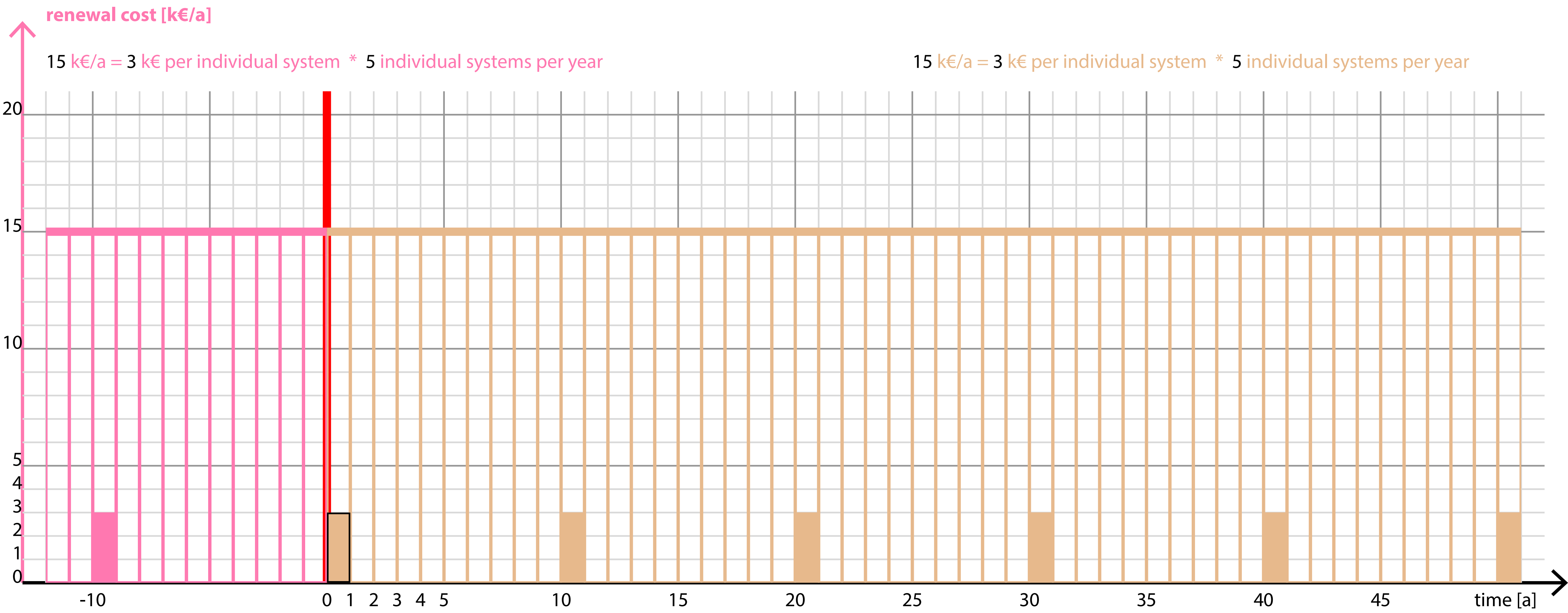


A -> B, optimised running costs (- 33 %)

after installing optimised systems all of a sudden







A -> B, optimised running costs (- 33 %)

after installing optimised systems within ordinary replacement cycle