0.15 m^2/MWh/a at the Min.AUX_{share}-optimal solutions. The optimal inclination angles of the solar collectors (β_{COL}) stayed at an angle of 45±4° for most of the community sizes, which is close to the latitude of Madrid. Moreover, the number of solar collectors connected in series remains at 4 for all optimal solutions. In the space heating circuit, the optimal characteristics of the SST at various community sizes show that the VSST is around 2.5 ± 0.5 m^3/MWh/a at the Min.cost solutions, and it extends to 12.5± 0.2 m^3/MWh/a at the Min.AUX_{share}-optimal solutions, whereas the HDR is around 0.7±0.05 m/m for all optimal solutions.

In the solar circuit, most of the optimal Pareto solutions at different community sizes remain the A_{COL} range between 0.4± 0.05 m^2/MWh/a for the Min.cost solutions and extend to 1.2 ± 0.15 m^2/MWh/a at the Min.AUX_{share}-optimal solutions. The optimal inclination angles of the solar collectors (β_{COL}) stayed at an angle of 45±4° for most of the community sizes, which is close to the latitude of Madrid. Moreover, the number of solar collectors connected in series remains at 4 for all optimal solutions. In the space heating circuit, the optimal characteristics of the SST at various community sizes show that the V_{SST} is around 2.5 ± 0.5 m^3/MWh/a at the Min.cost solutions, and it extends to 12.5± 0.2 m^3/MWh/a at the Min.AUX_{share}-optimal solutions, whereas the HDR is around 0.7±0.05 m/m for all optimal solutions.

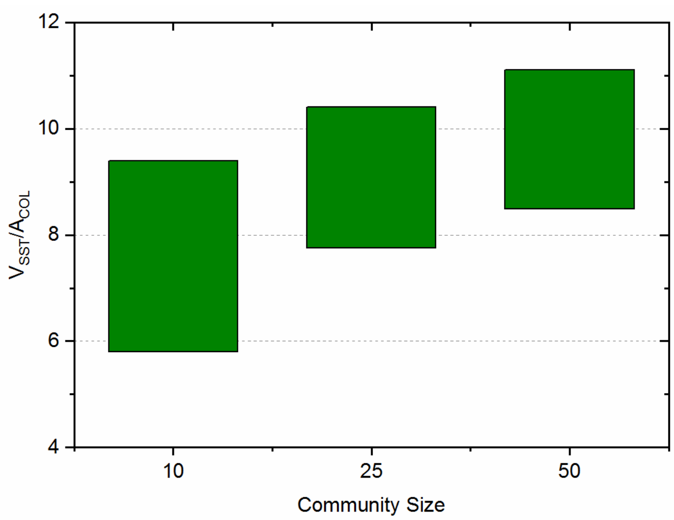

Fig. 3. The Seasonal storage tank volume to solar collector area ratio at different community sizes

In addition, Fig. 3 shows a summary for the proposed sizing of the A_{COL} and V_{SST} based on the Pareto optimal solution at various community sizes. With the increment in the community size, the upper and lower limits of the Pareto frontier solution increase where lower bounds are 5.6, 7.7 and 8.4 m^3/m^2 for the community size of 10, 25 and 50 building, respectively, Whereas the upper limits increase from 9.3 to 11.1 m^3/m^2 at investigated community sizes. In the DHW circuit, since the DHWT is used only for the daily purposes without long term storage, the histogram depicts that the V_{DHWT} is only around 0.15±0.06 m^3/MWh/a for most of the optimal solutions, whereas the HDR_{DHWT} diverge around 1.5 ± 0.2 m/m.

B. Economic performance

Following the Pareto optimal solutions at different community sizes, Fig. 4 depicts a detailed breakdown for the life cycle cost of the SDHS when introduced at different community sizes under the extreme scenarios (Min.cost-optimal solutions & Min.AUX_{share}-optimal solutions). The initial investment cost at all other community sizes is a quite significant cost component compared to operation and the replacement cost. This cost contribution is ascending increases with reducing the AUX_{share}. In the Min.cost-optimal solutions, the investment cost represents 50.2%, 47.6% and 46.7% for the community size of 10, 25 and 50 buildings, respectively. While in the Min.AUX_{share}-optimal solutions, the investment cost represents around 63% for all community sizes. To be more specific, the solar collector and SST have the main contribution to the initial investment cost.

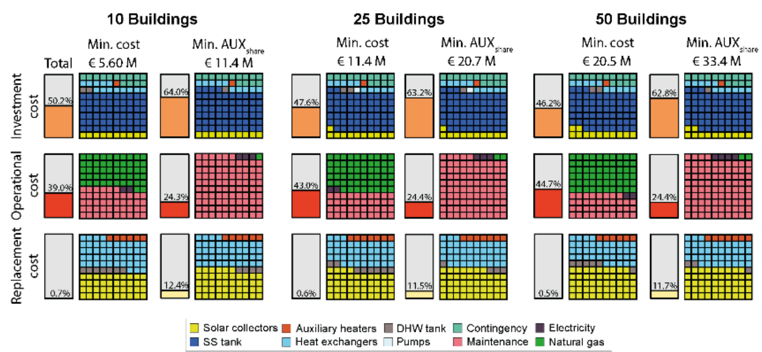

Fig. 4. Life cycle cost breakdown of Pareto optimal solutions for a SDHS system applied at various community sizes. The breakdown includes the shares of initial capital cost, operational cost, and replacement cost

On the other hand, the operational cost declines with the movement toward the Min.AUX_{share}-optimal solution where it represents 39%, 43% and 44.7% for the community size of 10, 25 and 50 buildings, respectively. Moreover, it declines to around 24% in the Min.AUX_{share}-optimal solutions, which implies the less usage of natural gas. To be more specific, the auxiliary heaters represents above 50% of the total operational cost in each community size at the Min.cost-optimal solutions, and it is reduced to around 1% for Min.AUX_{share}-optimal solutions. The replacement cost follows the same trends as the investment cost, where it represents about 0.5% in the Min.cost-optimal solutions, and it increases to around 12% in Min.AUX_{share}-optimal solutions due to the increment in the share of renewable energy equipment.

In addition to the economic breakdown, the payback period is proposed to measure the system feasibility throughout its lifetime, as shown in Fig. 5. the SDHS could not approve its feasibility in the community size of 10 buildings since it varies between 39.4 years and 66.6 years, which is higher than the lifetime of the SDHS. With increasing the community size, the payback period decreases progressively, where the payback period at the Min.AUX_{share}-optimal solution reduces to 32.2, and 28.8 years for the community size of 25, and 50 buildings, respectively.

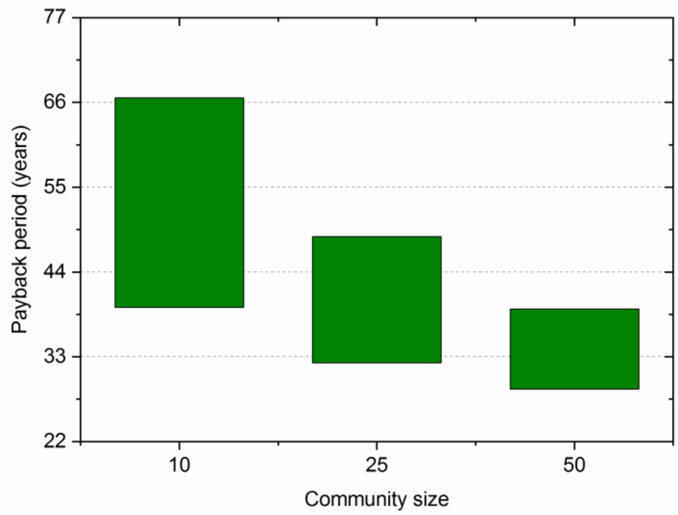

Fig. 5. Payback period bounds at different community sizes

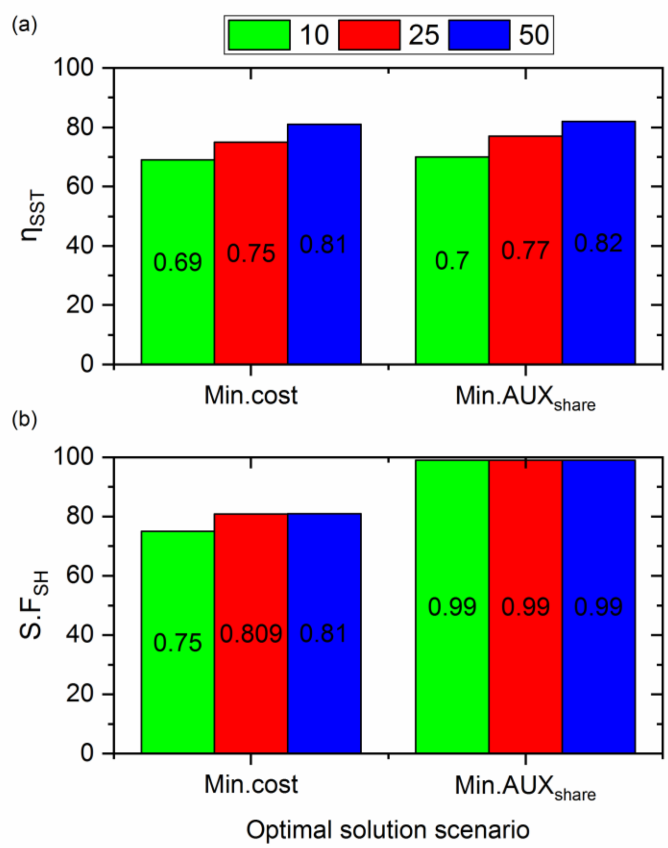

Fig. 6. The performance indicator including (a) η_{SST}, (B) $S.F_{SH}$ for the optimal Pareto SDHS solutions at different community size of 10, 25 and 50 buildings

C. Thermal performance

Finally, our methodology facilitates the analysis of the optimal configurations of a SDHS from the thermodynamic point of view based on the η_{SST} and $S.F_{SH}$ as shown in Fig. 6. In term of the η_{SST}, the SST efficiency rises with reducing the AUX_{share} where the η_{SST} in the Min.cost-optimal solution is 69%, 75.0%, and 81% for the community sizes of 10, 25, and 50 buildings, respectively. Moreover, this value increases slightly in the Min. AUX_{share}-optimal solutions to 70%, 77%, and 82% for the community size of 10, 25, and 50 buildings, respectively. While in terms of the $S.F_{SH}$, a value of 75% is indicated for a community size of 10 buildings. This value can be improved with the increment in the community size where $S.F_{SH}$ of 80.9%, and 82% is indicated for the community size of 25 and 50 buildings. With the movement toward the Min. AUX_{share} solutions, all optimal cases show that the $S.F_{SH}$ closes to 100%. On the other hand, the $S.F_{DHW}$ never falls below 98% for all community sizes.

V. Conclusion

In this study, a multi-objective optimization methodology is presented to evaluate the techno-economic feasibility of the SDHS at different urban communities located in Madrid; these residential communities include 10, 25, and 50 buildings. The main finding of this work is that the SDHS can bring both technical and economic benefits simultaneously, especially in the large the communities of 50 buildings. A summary for methodology key findings is the following:

- The Min.cost-optimal solutions demonstrate progressive improvement in the economic benefits of the SDHS with the increment in the community sizes where the NPC is improved by 19.1%, and 27.3% for community size of 25, and 50 buildings, respectively. While Min.AUX_{share} optimal solution, this improvement can extend to 27.5% and 41.6% for the 25 and 50 buildings, respectively.
- This improvement can be reflected in the payback period where it around 40 years for the community of 10 buildings, and it can be reduced to 32.2 and 29 years for the community size of 25 and 50 buildings.
- From the thermal point of view, the η_{SST} in the Min.cost-optimal solution is 69%, 75.0%, and 81% for the community sizes of 10, 25, and 50 buildings. Moreover, it can expand up to 82% in the community size of 50 buildings. While in terms of the $S.F_{SH}$, it never falls below 75% for all community sizes.

In general, this study has shown that SHDS can provide a significant contribution to the energy demand at the residential section, especially in large communities. However, more realized projects are needed to generate practical experience on system design and operation and to lower costs through increased market activity.

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